NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE SIMULATION-BASED ACQUISITION RESEARCH LABORATORY

by

Andrew J. DiMarco

December 1998

Principal Advisor:	David F. Matthews
Associate Advisor:	Michael L. McGinnis

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE December 1998	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE : The Simulation-Based Acquisition Research Laboratory

5. FUNDING NUMBERS

6. AUTHOR(S) Andrew J. DiMarco

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/ MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT This thesis examines the theoretical and practical aspects of simulation-based acquisition (SBA). SBA may provide the Defense acquisition community with a means to improve the acquisition process by reducing both cost and acquisition cycle-time, as well as leading to better system performance. In the past, the acquisition community applied computer models and simulations in a less-than-optimal manner. Recent use of computer models and simulations produced encouraging resource savings. However, the acquisition community has not yet fully realized the potential benefits of applying M&S to the acquisition process. This thesis also discusses lessons learned from application of SBA to commercial ventures that may help the Department of Defense develop an integrated set of computer models and simulations to improve weapon system acquisition across functional disciplines. Finally, this thesis discusses the need for an acquisition research laboratory and proposes a SBA laboratory environment as a means of further developing and implementing SBA.

14. SUBJECT TERMS Modeling and Simulation

15. NUMBER OF PAGES 88

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

Approved for public release; distribution is unlimited

THE SIMULATION-BASED ACQUISITION RESEARCH LABORATORY

Andrew J. DiMarco
Major, United States Army
B.S., State University of New York at Buffalo, 1987

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1998

Author: ______________________
Andrew J. DiMarco

Approved by: ______________________
David F. Matthews, Thesis Advisor

____
Michael L. McGinnis, Associate Advisor

____
Reuben T. Harris, Chairman
Department of Systems Management

ABSTRACT

This thesis examines the theoretical and practical aspects of simulation-based acquisition (SBA). SBA may provide the Defense acquisition community with a means to improve the acquisition process by reducing both cost and acquisition cycle-time, as well as leading to better system performance. In the past, the acquisition community applied computer models and simulations in a less-than-optimal manner. Recent use of computer models and simulations produced encouraging resource savings. However, the acquisition community has not yet fully realized the potential benefits of applying M&S to the acquisition process. This thesis also discusses lessons learned from application of SBA to commercial ventures that may help the Department of Defense develop an integrated set of computer models and simulations to improve weapon system acquisition across functional disciplines. Finally, this thesis discusses the need for an acquisition research laboratory and proposes a SBA laboratory environment as a means of further developing and implementing SBA.

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE

This thesis examines the theoretical and practical aspects of simulation-based acquisition as a method for acquisition reform. It reviews the current acquisition process, defines and describes the current simulation-based acquisition environment and critically assesses risks, benefits, and feasibility of a simulation-based approach. It discusses key areas where a program manager might consider using simulation-based acquisition as a method for developing and acquiring weapon systems. The thesis also explores requirements for developing a simulation-based research laboratory, and recommends a high-level architecture for the environment.

B. BACKGROUND

The current Department of Defense (DoD) environment of shrinking budgets and acquisition reform motivated DoD to reduce system acquisition outlays through cost, schedule, and performance tradeoffs. Decisions made early in the design of a weapon system account for most of the life-cycle costs (Sanders, 1997). Recent advances in inexpensive computing technologies, computers, and simulations may provide acquisition program managers with tools for dramatically reducing cycle-time and program costs.

Until recently, acquisition program managers primarily utilized computer models and simulations to improve product design decisions. In many instances, these decisions led to cost, schedule, and performance improvements. However, computer models and simulations were not usually viewed as integrated components for a product development

and acquisition management. In many cases, managers were unaware of improvements to computer models and simulation tools that they could utilize to benefit their programs.

Recent evidence suggests computer models and simulations may both reduce acquisition cycle-time up to 50% and lead to lower overall program costs (Sanders, 1997). Assuming this trend continues, simulation-based acquisition in the future will combine state-of-the-art computer simulations and communications technology to create an integrated, focused approach to weapon systems acquisition leading to a significant reduction in the flyaway and life-cycle costs of a weapon system.

C. THESIS OBJECTIVE

This thesis examines the simulation-based acquisition process and evaluates how a research laboratory environment might benefit program managers who exploit this acquisition strategy. It explores the use of computer models and simulations both in the Government and commercial sector. Risks and benefits associated with the application of computer models and simulations to the acquisition process are also addressed. It suggests and discusses areas where a program manager might follow a simulation-based acquisition strategy. Finally, this thesis proposes a high-level architecture for designing a simulation-based laboratory where program managers can apply simulation-based acquisition methods to their programs.

D. RESEARCH QUESTIONS

The primary thesis research question is:

1. How can a simulation-based laboratory assist acquisition managers?

Secondary research questions:

1. What is simulation-based acquisition?
2. What are the associated risks and benefits of a simulation-based acquisition strategy?
3. What key issues impact the use of simulation-based acquisition?

E. SCOPE AND LIMITATIONS

This thesis examines simulation-based acquisition from a management rather than a technical perspective. In doing so, it briefly overviews the current acquisition process and past attempts to reform and streamline the acquisition process. It then defines simulation-based acquisition, examines both DoD and civilian programs, and discusses risks and benefits of simulation-based acquisition. The thesis proposes a simulation-based acquisition laboratory architecture and suggests how it could benefit program managers. This thesis does not attempt to design specific models and simulations, or address unique programmatic situations.

F. RESEARCH LITERATURE AND METHODOLOGY

Research was conducted via personal, telephone, and electronic mail interviews with both program managers and modeling and simulation experts. Specifically, research data were gathered from official Government directives and policies, journals, previous theses, United States Code, DoD regulations, and personal interviews. Simulation-based acquisition information sources include the Defense Modeling and Simulation Office (DMSO), the Army Modeling and Simulation Office (AMSO), and the Army's Tank-

Automotive Command (TACOM). Commercial applications of modeling and simulation include Boeing and Lockheed Martin.

G. ACRONYMS

The appendix lists simulation-based acquisition acronyms used for this thesis.

H. ORGANIZATION OF THESIS

Chapter I contains the purpose, background, thesis objective, research questions, scope and limitations, and thesis organization.

Chapter II addresses the current acquisition process. It reviews related policies and laws and provides an overview of the process. This chapter concludes by discussing recent reforms to help streamline the process.

Chapter III provides a background on modeling and simulation and defines simulation-based acquisition. The chapter examines several applications of modeling and simulation to both Defense and commercial acquisition ventures and identifies risks and benefits associated with simulation-based acquisition.

Chapter IV overviews the laboratory environment and discusses implications for implementing a simulation-based acquisition laboratory. Finally this chapter suggests a high-level laboratory architecture.

Chapter V gives conclusions, recommendations, and suggests areas for further research.

II. DEFENSE ACQUISITON

A. INTRODUCTION

The Defense acquisition process provides a method for acquisition managers to procure weapon and information systems needed by our Armed Forces to deter or win wars. Schmoll provides this insight into the Defense acquisition process:

> The Defense acquisition system is a single uniform system whereby all equipment, facilities, and services are planned, developed, acquired, maintained, and disposed of by the Department of Defense (DoD). The system includes policies and practices that govern acquisition, identifying and prioritizing resource requirements, directing and controlling the process, contracting, and reporting to Congress. (Schmoll, 1996)

Defense acquisition provides warfighters with equipment necessary to fight and win on tomorrow's battlefields. As such, the process requires close coordination between DoD, users, acquisition managers, Congress, and the commercial sector. The Defense acquisition process translates a need or requirement into a tangible, usable, and useful system the warfighter can employ on the battlefield. Schmoll defines successful Defense acquisition as:

> A program that places a capable and supportable system in the hands of a user when and where it is needed, and does so within the bounds of affordability (Schmoll, 1996).

The remainder of this chapter focuses primarily on the management of Major Defense Acquisition Programs (MDAPs).

B. AUTHORITY FOR DEFENSE ACQUISITION

Defense acquisition authority and guidelines are found in a number of sources including Federal laws, Office of Management and Budget circulars, Federal regulations, and agency supplements to Federal regulations.

1. Federal Laws

Laws set forth by Congress provide the foundation for successful acquisition of materials and services that support Defense requirements. Key laws include Title 10 of the United States Code, DoD Procurement Reform Act (1985), DoD Reorganization Act of 1986 (Goldwater-Nichols Act), and the Federal Acquisition Streamlining Act (FASA) of 1994.

2. Office of Management and Budget Circular A-109

Office of Management and Budget (OMB) Circular A-109 establishes overarching acquisition policy for all Federal organizations. It directs all Federal agencies to establish clear management authority by designating a program manager (PM) for each acquisition. Further, it requires competitive exploration of alternative systems.

3. Federal Acquisition Regulation

The Federal Acquisition Regulation (FAR) governs the acquisition of supplies and services by all Federal organizations. This regulation broadly defines acquisition policy while allowing individual organizations to tailor the guidance to their specific needs. It provides a procurement framework based on sound business practices to assist the PM in acquisition management.

4. Agency Supplements

Federal agency supplements tailor the FAR by further defining how agencies accomplish product and service acquisition. Agency Supplements to the FAR provide employees with specific guidance for conducting acquisition management. For example, the DoD 5000 provides key policy and defines procedural language for Defense acquisition. It applies to all Defense acquisitions but, in particular, addresses MDAP management. Within this series, two key documents that guide Defense acquisition are DoD Directive 5000.1 and DoD Regulation 5000.2-R.

a. DoD Directive 5000.1

DoD Directive 5000.1 provides guidelines for acquiring all materials and services. It establishes broad policy and underlying principles that provide for the integrated management of all Defense procurements. DoD Directive 5000.1 highlights three principles critical to the success of an acquisition program: translating operational needs into stable and affordable programs, acquiring quality products, and organizing for efficiency (Schmoll, 1996).

b. DoD Regulation 5000.2-R

DoD Regulation 5000.2-R mandates policies and procedures for the acquisition of MDAPs. The regulation provides procedural guidance for six key acquisition management areas (Schmoll, 1996).

- *Acquisition Management Process:* Provides a general model for MDAP management.

- *Program Definition:* Provides guidance for translating broad needs into well-defined performance specifications.

- *Program Structure:* Identifies elements such as objectives and thresholds, contract type, and Cost As an Independent Variable (CAIV) necessary to configure a successful program.

- *Program Design:* Establishes the basis for a structured and disciplined approach to MDAP life-cycle management through the use of Integrated Product and Process Development (IPPD) and the systems engineering process.

- *Program Assessment and Decision Reviews:* Establishes mandatory policies and procedures for conducting periodic assessments and milestone decision reviews.

- *Periodic Reporting:* Describes mandatory reports, and in some cases provides report formats required by oversight agencies such as Acquisition Executives (AEs) and Congress.

C. THE DEFENSE ACQUISITION PROCESS

Defense Acquisition is event-driven. It follows a structured, yet tailorable, approach to developing, fielding, and disposing weapon systems.

1. Overview of Acquisition-Based Methodologies

Program managers may utilize several methods for managing an acquisition program. These include: traditional, grand design, incremental, and evolutionary methodologies. Each acquisition methodology is briefly described below.

Traditional. The Traditional methodology serves as DoD's baseline approach for MDAP acquisition. It follows a linear, phased approach for managing programs. This methodology is generally used for high-risk MDAP acquisition. This methodology typically takes up to 15 years to acquire a weapon system.

Grand Design. The Grand Design methodology is utilized when requirements are well-defined and additional design improvements are not needed. All requirements for system acquisition, development, and deployment are conducted in one step.

Incremental. PMs utilize the Incremental methodology when requirements are well-defined, but other acquisition processes, such as funding, are less certain. PMs field the system in a series of increments, or blocks, with increasing functionality over time rather than fielding a fully functional system at a single point in time. This methodology is characterized by a "build-a-little, test-a-little" approach that delivers a functional subset of the final capability at the initial and subsequent blocks.

Evolutionary. The evolutionary methodology is characterized by the design, development, and deployment of a capability using currently-available technologies, but also includes provisions for the addition of future capabilities as the requirements and technologies mature. This methodology is often utilized when the requirements are not fully defined, but evolve over time as the system is designed, developed, and prototyped. Often this approach is best suited to situations where detailed system or operational requirements are difficult to articulate. Advanced Technology Demonstrations (ATDs) can employ this approach.

2. Baseline Methodology

This section focuses on the baseline methodology by discussing the components associated with it. Note that the components are also common to other acquisition methodologies but may not be completed in the same sequence. Phases correspond to time periods during which activities occur that contribute to a common outcome. Milestones act as decision points, allowing an approval authority to make an informed decision whether to move into the next phase. Figure 1 depicts the elements that are considered at each milestone. These phases and milestones may be repeated to create a

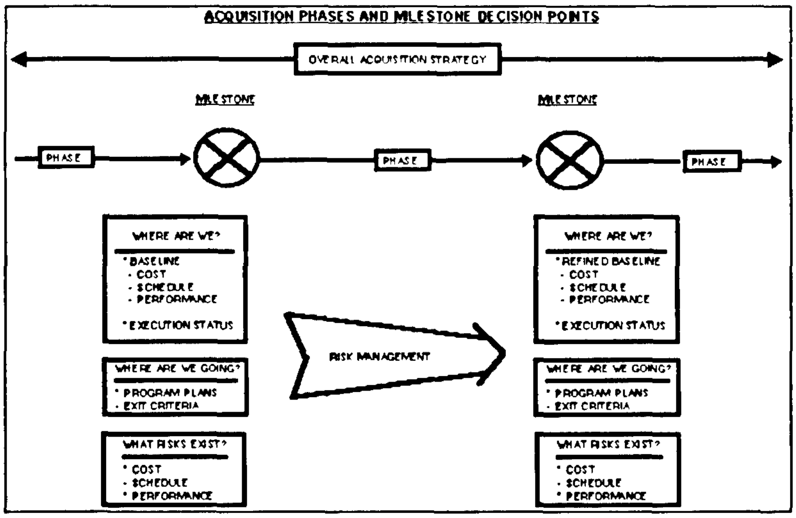

Figure 1. Acquisition Phases and Milestones (DoD Acquisition Deskbook, 1998).

specific acquisition process structure. Figure 2 depicts the baseline acquisition methodology. This methodology consists of four phases and milestones.

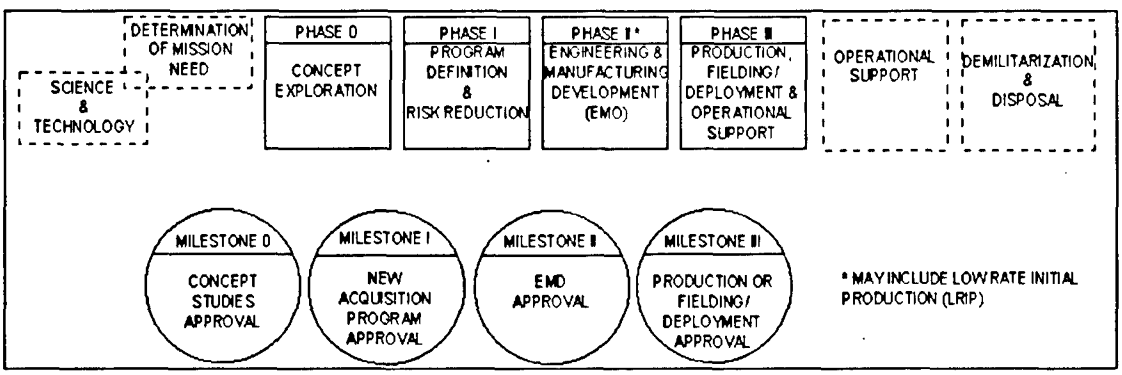

Figure 2. The Baseline Acquisition Methodology (DoD Acquisition Deskbook, 1998).

a. Pre-phase 0

Pre-phase 0 activities involve the determination of a mission need as depicted in Figure 2. Pre-phase 0 begins with a Mission Area Analysis (MAA) which is an examination of current and projected DoD capabilities, future threats, changes in policy, as well as an analysis of technological advancements in a particular category. The

MAA, conducted by organizations such as the US Army Training and Doctrine Command (TRADOC), may examine areas such as tank warfare. If the MAA identifies a deficiency or weakness in this category, a non-material solution is sought. Changes to doctrine or tactics may be all that is required for the non-material solution. If an acceptable non-material solution is not available, a mission need statement (MNS) is developed. The MNS document formally states the requirement for a material solution. Once the MNS is completed it must be validated. For a MNS that will lead to a MDAP, the Joint Requirements Oversight Council (JROC) is the validation authority. For non-MDAP MNS, validation authority may be delegated as low as Commanders-in-chief (CINCs) of unified commands. Upon validation the MNS is sent to the Under Secretary of Defense (Acquisition and Technology) (USD(A&T)) for a Milestone 0 decision.

b. Milestone 0

Milestone 0 consists of the approval by the USD(A&T) or other appropriate Milestone Decision Authority (MDA) to proceed into Phase 0 and conduct concept studies. The MDA specifies a minimum set of alternatives to be studied, the lead organization, and the exit criteria for Phase 0.

c. Phase 0

Phase 0 consists of concept exploration. Alternative concepts are studied to determine their feasibility. Phase 0 is characterized by competitive and parallel studies that provide the data necessary to assess the merits of each concept. Phase 0 usually lasts about 1 to 2 years. (Schmoll, 1996)

d. Milestone I

Approval to begin a new acquisition program occurs at Milestone I. The MDA approves the acquisition strategy and baseline that allows for the entry into Phase I. Other objectives, such as CAIV and exit criteria for Phase I, are also defined. (Schmoll, 1996)

e. Phase I

Phase I is Program Definition and Risk Reduction (PDRR). It focuses on mitigating risk through various methods such as early prototyping and cost-performance trade-offs. The PM identifies cost-drivers, interoperability issues, and alternatives to the acquisition strategy. This phase can last upwards of 5 years, especially if prototyping is conducted. (Schmoll, 1996)

f. Milestone II

The MDA gives approval to enter the engineering and manufacturing development phase at this milestone. The acquisition strategy and baseline are revisited and approved, exit criteria established for Phase II and quantities identified for low rate initial production (LRIP). (Schmoll, 1996)

g. Phase II

Engineering and Manufacturing Development (EMD), or Phase II, ensures the designed system is ready for manufacturing. To accomplish this, a number of certifications must occur including a design review and production process validation. This phase also encompasses testing in the form of Developmental Test and Evaluation

(DT&E). The system is ready to enter into Phase III when the early prototype or final design is approved and the manufacturing processes are validated. (Schmoll, 1996)

h. Milestone III

The production decision is made at Milestone III. The MDA reviews and approves the acquisition strategy and baseline. The decision at this milestone allows the program to enter full-rate production.

i. Phase III

Phase III, the longest of all phases, encompasses a variety of activities. Not only are the systems produced during this phase, but all fielding, operational support, and disposal activities are covered as well. As the system is produced, additional testing is conducted primarily in the form of Operational Test and Evaluation (OT&E) which allows an independent assessment of the system's effectiveness and suitability. This testing is generally conducted in a live setting. Once the system is fielded, issues such as modifications to sub-components are dealt with on a case-by-case basis. Additionally, as the system begins to wear out or a replacement is fielded, demilitarization and disposal of the system is overseen by the PM. This helps ensure that environmental, safety, and security issues are considered and applied.

C. ACQUISITION REFORM

Over the last 50 years the process of developing and acquiring weapon systems has become complex and inefficient often characterized by cost overruns and fifteen-year procurement cycles. Dr. Kaminski, the USD (A&T) in the 1990s, noted that:

> New national security challenges require DoD to design a more flexible, agile, and timely acquisition system capable of meeting unpredictable threats. This means that the DoD acquisition system must improve it's support to the war fighter by reducing the acquisition cycle time and leveraging the latest available technologies, particularly information technology (Kaminski, 1997).

Throughout the past 50 years, numerous attempts were made to change the way DoD procured weapon systems. It was not until the 1990s that a number of initiatives were successful in reducing the cost and cycle-time associated with acquisition. Schmoll notes that unlike previous decades, the 1990s:

> Can be characterized as an era with declining Defense budgets, smaller workforces, and significant changes in threat to national security (Schmoll, 1996).

These factors, combined with the visionary leadership by persons such as the then Secretary of Defense Dr. William Perry and Dr. Kaminski, as well as the adoption of key legislation, created an environment that allowed acquisition reform to take place.

1. Legislation

Section 800 of Public Law 101-510 provides the basis for acquisition reform in the 1990s. This Act established a framework that included the following goals: streamline the Defense acquisition process, eliminate unnecessary acquisition laws, ensure the financial integrity of defense procurement programs, and protect the best interests of DoD. (Schmoll, 1996)

Two additional legislative documents provide more concrete direction for implementing changes to Defense acquisition. The Federal Acquisition Streamlining Act of 1994 and the National Defense Authorization Act of 1996 outlined changes to the

acquisition process that assisted in making acquisition reform a reality. These changes attempt to streamline the acquisition process by reducing overall program complexity, cost, and cycle-time.

2. Initiatives

DoD has undertaken many initiatives since these Acts took effect. Some key initiatives are described below:

a. Electronic Commerce / Electronic Data Interchange

The Electronic Commerce / Electronic Data Interchange (EC/EDI) initiative facilitates the conduct of business transactions and the exchange of information electronically. DoD and commercial entities can complete the contracting, payment, and data exchange processes through the use of electronic media and in some cases via the internet. EC/EDI eliminates massive amounts of paperwork, facilitates instant communications, and automates bulk transaction processing.

b. Integrated Product and Process Development

The Integrated Product and Process Development (IPPD) initiative attempts to remove barriers that existed from both an inter- and intra-Program Management Office (PMO) perspective. Previously, PMOs operated in a stove-piped fashion, with each functional discipline, such as finance or engineering, essentially operating on their own. This led to inefficiencies in communication and in accomplishment of tasks due to the compartmentalized nature of the PMO. IPPD creates an environment for individuals of specific functional disciplines to meet together to collectively plan and execute a particular task. In doing so, cross-functional problems are

resolved early-on and information flows both horizontally and vertically through the PMO. Additionally this initiative brings DoD and the contractor together to work side-by-side in the development of the product.

c. Single Process Initiative

This initiative attempts to eliminate or consolidate redundant specifications that a contractor must utilize to satiate the requirements from different Services or commercial sectors for the same product. By eliminating or reducing numerous variations on a particular specification or standard, the costs of maintaining, overseeing, and producing products under multiple specifications or standards is reduced.

d. Simulation Test and Evaluation Process Improvements

A number of activities are directed at reducing the cost and duration of conducting operational testing on emerging systems. The Simulation Test and Evaluation Process (STEP) improvements are aimed at bringing the operational test community into a program as early as possible. Working under the concept of IPPD, these improvements consolidate developmental and operational testing and inject more computer modeling and simulation into the testing program. Through the consolidation of these tests, reductions in cycle-time and costs are attained.

D. SUMMARY

This chapter examined and discussed the Defense acquisition process. It provided an overview of the process and some recent initiatives aimed at streamlining an often complex and inefficient process. It provides a foundation for understanding the complexity associated with the acquisition process and the need for reform in a time

when defense budgets are declining and the geopolitical environment has significantly changed. Chapter IV examines how simulation-based acquisition can answer the call for acquisition reform and provide the PM with a method for decreasing costs, cycle-time, and improving performance.

III. SIMULATION–BASED ACQUISITION

A. INTRODUCTION

DoD supports applying modeling and simulation across a wide range of disciplines. Historically, DoD primarily utilized modeling and simulation to support training and operational assessment. Recently, the DoD acquisition community focused on utilizing computer models and simulations for developing, designing, and manufacturing weapon systems. This concept, now referred to as *Simulation-Based Acquisition* (SBA), represents an effort to fully integrate modeling and simulation technology across all acquisition functions and phases.

B. REGULATIONS AND GUIDANCE

The DoD 5000 series emphasizes the use of modeling and simulation technology. DoD Directive 5000.1 states:

> Models and simulations shall be used to reduce time, resources, and risks of the acquisition process and to increase the quality of systems being acquired. Representations of proposed systems (virtual prototypes) shall be embedded in realistic, synthetic environments to support the various phases of the acquisition process, from requirements determination and initial concept exploration to the manufacturing and testing of new systems, and related training (DoD Directive 5000.1, 1996).

DoD Regulation 5000.2-R mandates the use of modeling and simulation when appropriate:

> Accredited modeling and simulation shall be applied, as appropriate, throughout the system life-cycle in support of various acquisition activities: requirements definition, program management, design and engineering, efficient test planning, result prediction, and to supplement actual test and evaluation, manufacturing, and logistics support. PM's shall integrate the use of modeling and simulation within the program planning activities, plan for life-cycle application, support, and reuse

> models and simulations, and integrate modeling and simulation across the functional disciplines (DoD Regulation 5000.2-R, 1998).

DoD Directive 5000.59-P provides a broad framework for applying computer models and simulations across the DoD acquisition process. It emphasizes the following key point:

> Defense modeling and simulation will provide readily available, operationally valid environments...to support technology assessment, system upgrade, prototype and full-scale development, and force structure (DoD Directive 5000.59-P, 1995).

This Directive further states:

> Common use of these environments will promote a closer interaction between operations and acquisition communities... and modeling and simulation environments will be constructed from affordable, reusable, components interoperating through an open systems architecture (DoD Directive 5000.59-P, 1995).

Finally, DoD 5000.59 delineates responsibilities for managing acquisition-based models and simulations and establishes the Defense Modeling and Simulation Office (DMSO) as the key integrator of models and simulations for the research, development, and acquisition domains (DoD Directive 5000-59, 1994). The DoD 5000 series points out that use of modeling and simulation technologies may greatly assist acquisition professionals in developing and delivering less expensive, yet more effective, weapon systems to the warfighter. Each regulation cited above recognizes, in its own way, the positive benefits and value-added of modeling and simulation applied to SBA.

High-level DoD support for using modeling and simulation in SBA comes from officials such Dr. Jacques S. Gansler, the USD(A&T). In comments to the 1998 National

Defense Industrial Association (NDIA) Simulation-Based Acquisition Workshop, Dr. Gansler states:

> I believe the payoff from acquisition modeling and simulation is now, not far off into the future…As more and more of our acquisition workforce 'buy in' to the notion that modeling and simulation can pay big dividends – both in terms of reduced cycle time and reduced costs – the barriers to this impressive technology will collapse (Gansler, 1998).

He further observed that the Defense acquisition community has not yet fully recognized the potential benefits of modeling and simulation:

> ...the potential here is enormous – especially in linking performance and costs together, going through the details of design, production and support (Gansler, 1998).

Other key individuals who, based on public statements, favor the use of SBA include Dr. Patricia Sanders, Director, Defense Test, Systems Engineering and Evaluation, and Dr. Herbert Fallin, Director, Assessment and Evaluation, Office of the Assistant Secretary of the Army for Research and Development.

C. MODELS AND SIMULATIONS

The Defense Systems Management College (DSMC) defines a model as a physical, mathematical, and logical representation of a system, entity, phenomenon, or process (Mercer, 1994). One can readily understand the category of physical models. For instance, a child who builds a 'model' airplane creates a physical representation of the actual airplane. In industry, however, system developers often create very complex computer models of real world systems and processes. This gives them the capability, for example, to fully design a product using a computer to depict its components from two or

three-dimensional viewpoints. The DoD acquisition community hopes to leverage these same methods to design and develop future military weapon systems.

DSMC defines simulation as a method for implementing a model over time; and a technique for testing, analyzing, or training in which real-world systems are used, or where real world and conceptual systems are reproduced by a model (Mercer, 1994). Computer simulations allow engineers and analysts to examine system behavior in much less time than it would actually take to evaluate a system prototype in a live environment. Simulations also save valuable resources of time, manpower, and money. For example, through the use of computer simulation, a pilot can fly an aircraft prototype through near-realistic, albeit, simulated conditions without requiring development of an actual aircraft. Many of today's video games illustrate this type of simulation.

The term, modeling and simulation (M&S), refers to the use of models, including emulators, prototypes, simulators, and simulations to generate data as a basis for making managerial or technical decisions (DoD Acquisition Deskbook, 1998). Throughout this thesis, M&S refers to the collective use of models and simulations according to this definition. Within this context, it is important that program managers understand that the M&S used for making decisions are only as good as the algorithms, framework, and inputs used to design and run the models and simulations.

Models and simulations may be categorized into three broad classes as depicted in Figure 3. Engineers and analysts generally develop and use computer-based constructive models and simulations. High-level simulations generate data on large-scale battles or

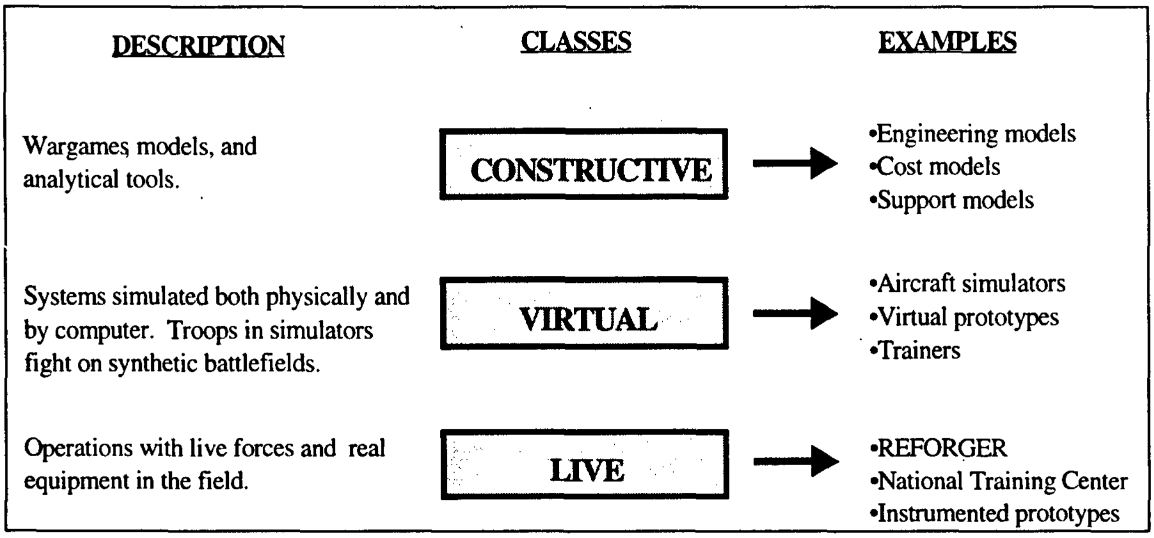

Figure 3. Classes of Models and Simulations (Mercer, 1994).

campaigns while lower-level models render specific design or cost data. The acquisition community currently uses constructive models for weapon system development.

Virtual simulations merge an actual system, subsystem, or virtual prototype with humans in a synthetic environment. This includes, for example, "man-in-the-loop" operating an aircraft or tank simulator at a stationary location in a computer-generated environment.

Live models or simulations include training exercises where participants perform actions and operations short of combat. Soldiers operate assigned equipment under realistic conditions. Examples of live simulations range from Return of Forces to Europe (REFORGER), to Louisiana Maneuvers, to simple, platoon-level training exercises in

local training areas. Currently, operational testing mostly relies on live simulation. The purpose of all three types of models and simulations is to gather data on the performance of a system or process in peacetime, so leaders or managers can more thoroughly understand how the system or process will perform under combat conditions.

One may also categorize models and simulations based on a hierarchical view of military operations. Models and simulations of different levels of military operations vary greatly in their ability to show detail. Mercer describes four levels of military models and simulations: theater/campaign, mission/battle, engagement, and engineering (see Figure 4 below).

At the theater level, models and simulations assess joint or combined operations. They generally give "big-picture" outcomes of interactions between large forces while varying equipment and capabilities. At the mission level, the focus narrows to a force package, manned and equipped to accomplish a specific mission. At lower engagement levels, simulations support studies comparing one weapon system against another. For example, simulation data may be generated for an engagement between a United States M-1 and a Russian T-81 tanks. Engineering-level models depict the greatest level of detail. Among other things, engineering models examine design, cost, human-machine interface, and manufacturing options. Engineering-level models assist managers in evaluating specific performance criteria of an individual component or sub-component.

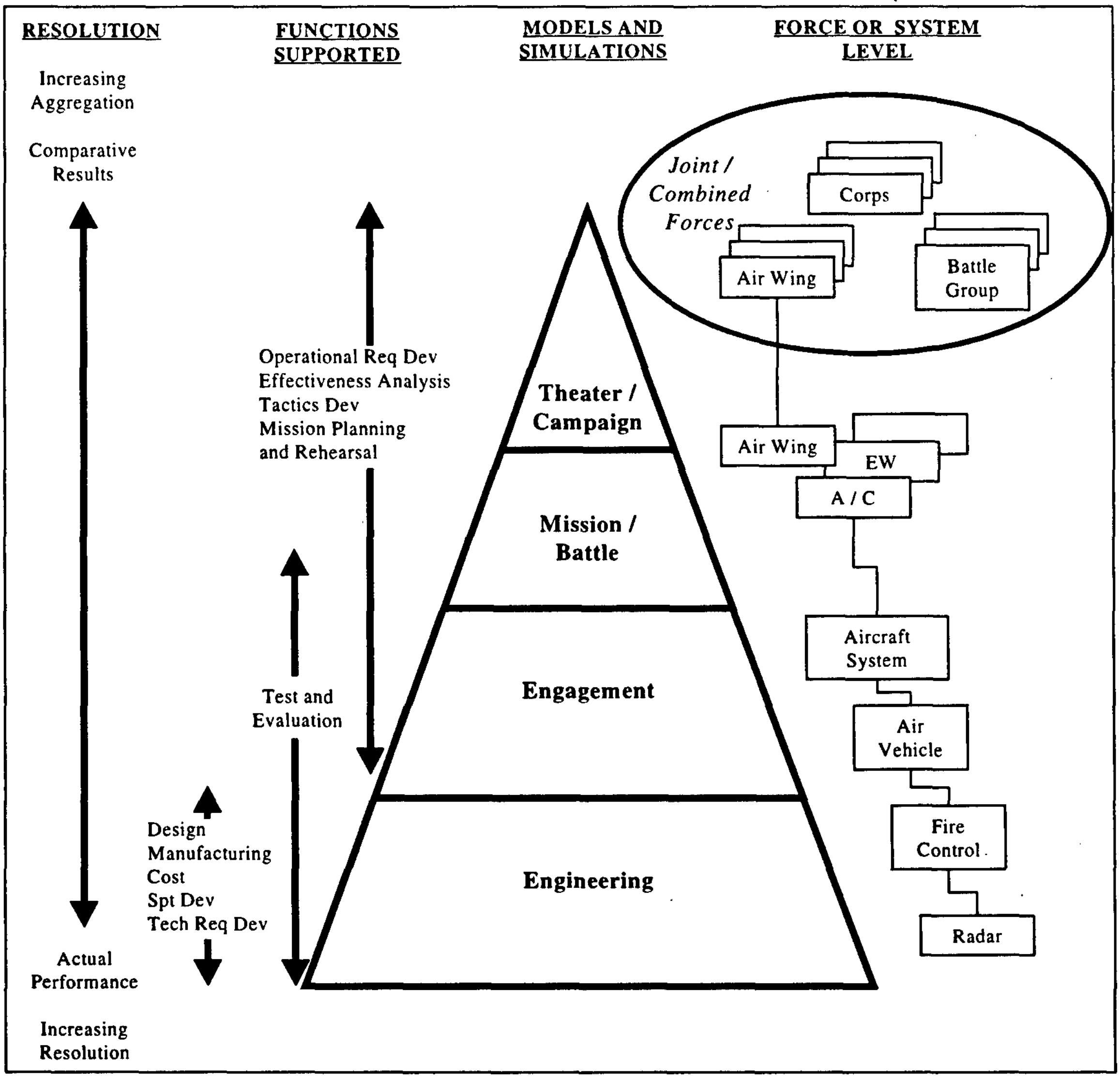

Figure 4. Hierarchy of Models and Simulations (Mercer, 1994).

The previous discussion presented an overview of model classes and simulations of different levels of military operations. The development of robust internet browsers and improved communications opened new opportunities for creating hybrid simulation environments. In the future, program managers may use hybrid simulations to create unique simulation environments to support acquisition processes. Mercer identifies

several hybrids consisting of multiple classes, hardware and software combinations, and simulation environments (Mercer, 1994):

- *Distributive Simulation.* This concept represents the ability to link different types of simulators across geographically dispersed locations.

- *Stimulation.* Computer models or simulations provide data that feeds directly to an actual system. This data provides simulated threats or other phenomena for testing a weapon system.

- *Hardware/Software-In-The-Loop (HW/SWIL).* HW/SWIL combines system hardware, multiple classes of models or simulations, and external stimuli. This environment demonstrates a systems capacity to operate within an environment that simulates actual conditions. The Guided Weapons Facility (GWEF) at Eglin Air Force Base is one example HW/SWIL.

D. APPLICATION OF MODELS AND SIMUALTIONS TO THE ACQUISITION PROCESS

M&S can potentially support all phases of the acquisition process. Prior to Phase 0, engineering models provide insight into performance aspects of new system designs, while campaign or mission level simulations can assist in evaluating the consequences of implementing the new technology prior to production. During Phase 0, engineering-level models and simulations may assist managers in conducting cost and operational effectiveness studies to support the analysis of alternatives. Mission and theater-level simulations may provide data for evaluating system effectiveness and performance. Program managers may use human-interactive simulations to examine and revise tactics and doctrine, resulting from the application of a new technology in system design (Mercer, 1994). Also during Phase 0, program managers prepare the Simulation Support Plan (SSP). The SSP outlines how program managers plan to utilize M&S throughout

the program. The SSP also assists program managers with planning and implementing M&S technologies throughout the life-cycle of the weapon system.

During Phase I, program managers may use models and simulations to identify and solve technical problems early in the acquisition process. Design and production improvements may be achieved through the use of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) linked to constructive and virtual simulations of production facilities. Simulations of production facilities may improve planning production processes and scheduling production. Cost models that incorporate engineering life-cycle costs may help evaluate alternatives presented in the analysis of alternatives. Simulations may provide data for early performance assessments during this phase instead of requiring contractors to produce data using prototypes (Mercer, 1994).

In Phase II, engineering-level models may be used to assess designs, design changes, capability trade-offs, test planning and support, subsystem and system performance, and verification of specification compliance. Computer models and simulations also support developmental test and evaluation, operational test and evaluation, as well as production and fielding (Mercer, 1994). Program managers may use HW/SWIL for pretest planning, execution, and analysis. This will help identify hardware problems prior to conducting live tests. Models and simulations seem well suited to support logistical and human support analyses by providing data on system reliability, availability, and maintainability. Engineering model data on LRIP hardware further support cost analysis. A combination of engineering, engagement, mission, and

campaign simulations may assist live simulations of both developmental and operational test and evaluation.

In Phase III, M&S supports testing, operator training, development of tactics, techniques, and procedures, and reevaluating design changes. Live simulations support OT&E ensuring the actual system meets required specifications and performance parameters. Virtual simulations assist in training system operators and maintainers and also contribute to mission rehearsal. Engagement, mission, and campaign-level models and simulations may assist in developing or refining tactics and doctrine. Finally, engineering-level models and simulations may provide insights into production and performance prior to the PM implementing design changes. The next sections discuss how acquisition managers applied M&S to the acquisition process in the past and implications of using M&S in the future.

E. HISTORICAL APPLICATION OF MODELS AND SIMULATIONS

In the past, acquisition managers applied M&S to the acquisition process with varying success. Figure 5 depicts how program managers utilized M&S prior to SBA. According to Karangelen (1997), program managers viewed M&S as a collection of disconnected applications that provided limited decision-making support to very specific functional domains. M&S was not integrated into the acquisition process, causing significant delays when using them to evaluate acquisition milestone decisions. Poor communications connectivity, and the lack of a functionally integrated environment added to this delay. Although program managers often attempted to apply M&S

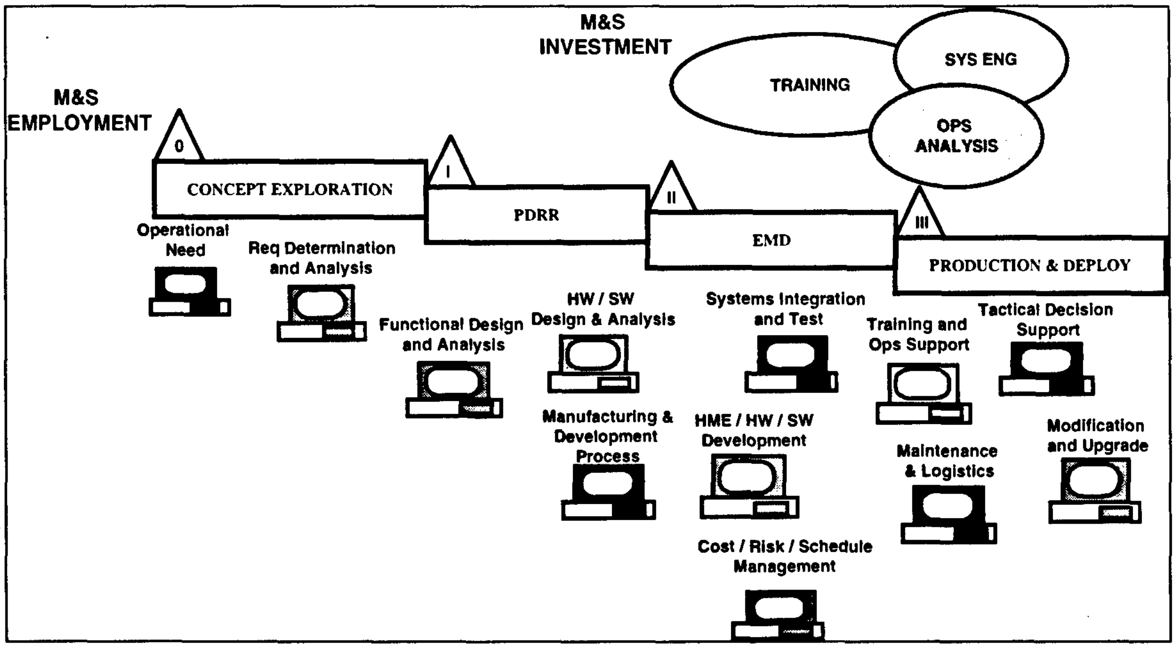

Figure 5. M&S and the Acquisition Process (Karangelen, 1997).

throughout the entire acquisition process, they primarily invested in M&S that supported training and operational analysis issues.

From early results, acquisition clearly benefited from modeling and simulation applications. System engineers recognized the value of using CAD tools to design systems in computer environments. These tools made it possible to easily and quickly generate two or three-dimensional designs to help contractors and warfighters visualize the system. CAD allowed designers to design, change, and evaluate drawings in a fraction of the time it normally took draftsman to draw blueprints by hand. This modeling environment conserves substantial resources required previously to design a system (Gansler, 1998). CAD also provided insights into problems caused by interference. Interference refers to instances where system parts or components physically occupy the same location causing manufacturing problems. Through CAD

methods, engineers can check for interference prior to building the system saving program managers time and resources.

Simulations, combined with cost models, support analysis of production processes and schedules, performance tradeoffs, and logistical and maintenance requirements. An October 1996 study, commissioned by Dr. Patricia Sanders, identified a number of benefits from applying M&S to key acquisition areas: concept development, engineering design and analysis, test and evaluation, manufacturing, and deployment and support processes. The report highlighted where M&S benefited acquisition programs in the past (Sanders, 1996):

> • *Concept Development.* DoD cancelled proposed development of the Wide-Area, Anti-Armor Munition (WAAM) and the JP-233 Runway-Attack Munition by identifying poor lethality potential. This resulted in a cost avoidance of $84M that may have been otherwise used to develop systems that did not meet user requirements or expectations.
>
> • *Engineering Design and Analysis.* Using the CAD environment, the Tank Automotive Research, Development, and Engineering Center (TARDEC) designed a new, low-silhouette tank prototype using 14 engineers in 16 months, as opposed to the normal 55 engineers in three years. In another example, Sikorski Aircraft employed 38 draftsmen and 6 months to produce working drawings of the CH-53E Super Stallion's outside contours, while the M&S environment employed in the Comanche program required only one engineer to do the same task in 1 month.
>
> • *Test and Evaluation.* Program managers accomplished bridge durability testing by conducting 3000 actual crossings at a cost of about $325K over a 12-month time frame. The combined use of constructive and real [live] simulations for this testing yielded cost savings of approximately $110K and a schedule reduction of approximately two months. The Moving Target Simulator (MTS) assesses the ability of tanks to engage moving targets in a simulated environment. It saves the Army approximately $1.5M annually compared with running live field tests.

- *Manufacturing.* The Joint Strike Fighter (JSF) program reconfigured a component, which originally contained 250 parts, to just 25 parts. This made it much easier to manufacture. The Army's use of the Flexible Computer-Aided Integrated Manufacturing (FCIM) program in electronics manufacturing led to a 66% reduction in cycle-time, $3M in cost savings, and $3.8M in cost avoidance.

- *Deployment and Support.* Electronic provisioning by Northrup reduced release time from six months to 60 minutes. The AH-64D Longbow Program utilizes a simulation to provide for high complexity maintenance training in a simulated environment, greatly contributing to the efficiency of maintenance personnel in the field.

Although these examples illustrate benefits of using M&S in Defense acquisition, problems still exist with M&S that impact program management. Notable problems include:

- Specialized M&S tools offering limited reuse potential;
- Lack of interoperability between models and simulations;
- No centralized M&S database;
- Unavailability of inexpensive, sophisticated, and high performing computing technologies;
- Inaccessible high-speed distributive communications environment.

From a management perspective, these M&S shortfalls inhibit development of a mature and robust SBA paradigm.

The lack of a focused Integrated Product and Process Development (IPPD) environment limits sharing information across functional areas. As functional experts developed unique M&S applications to support their needs, they neglected to plan for

M&S connectivity with other systems or reuse. The reuse issue applies to both intra-program and inter-program functional domains.

A lack of M&S and computer science training and communication through out the acquisition community made it difficult for program managers to capitalize on the potential benefits of applying M&S across all functional domains and phases of the acquisition life-cycle. The acquisition community simply did not understand how the analysis, testing, and M&S communities used live experiments or constructive simulations such as JANUS, CASTFOREM, VIC, or Eagle to support force development studies. Therefore, the acquisition community failed to fully comprehend the benefits of applying constructive and virtual models and simulations to the acquisition process.

The belief by some key leaders within the acquisition community that M&S could not produce accurate and reliable data also contributed to the problem (Sanders, 1996). Consistent and practical guidelines outlining methods for validating and verifying models and simulations for acquisition did not exist. For these reasons, organizations such as OT&E resisted the use of constructive and virtual M&S relying, instead on expensive, time and resource intensive live exercises.

Technology constraints also limited the use of M&S for acquisition. Collaborative, constructive, and virtual M&S require fast computers and highly sophisticated software applications. Until recently, no DoD M&S architecture existed for development of an integrated model and simulation environment enabling systems to communicate with each other. The lack of high-performing, inexpensive computers also

made it difficult to integrate distributed M&S. For these reasons, managers generally stove-piped models and simulations within a narrow application domain.

Finally, an immature information technology environment also inhibited application of models and simulations. A lack of reliable, economical, high-speed data exchange and communication systems meant program managers could not access large bandwidths needed for distributed communications. This restricted the use of M&S to specific locations making it necessary for acquisition team members to travel to the M&S testing site.

F. SIMULATION-BASED ACQUISITION

Over time, the M&S and acquisition communities worked together to overcome the shortcomings of applying M&S to the acquisition process. This led to a new paradigm -- Simulation-Based Acquisition. The American Defense Preparedness Association defines SBA as:

> An advanced engineering environment that includes formal methods, tools, and a common standard. It provides the means for executing an extensible, tailorable, and repeatable process that results in creation of reusable design repositories and re-engineerable products. It is a comprehensive integrated systems engineering environment coupled with an iterative acquisition process and an evolved culture (Portman, 1996).

Portman (1996) describes SBA as:

- An advanced engineering environment which utilizes formal methods, tools, and representations.
- A tailorable, iterative acquisition process.
- An Integrated Process and Product Development (IPPD) environment that includes refined roles and responsibilities of key acquisition personnel and agencies.

The SBA paradigm relies on all types of M&S, however, it focuses mainly on the use of constructive and virtual models and simulations to reduce the level of resources previously required to conduct live M&S. Fully leveraging this paradigm in the future

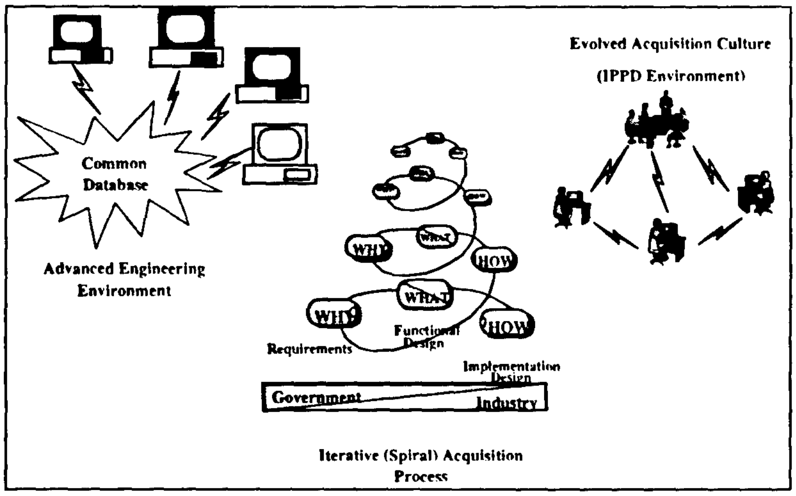

Figure 6. SBA Elements (Karangelen, 1997).

will mean program managers must address technological barriers that precluded the use of M&S in the past. Figure 6 depicts key M&S components.

First, the acquisition community must integrate multiple M&S applications. That is, computer models and simulations must seamlessly support all acquisition phases and disciplines. Computer models and simulations must share common databases and communication protocols. Figure 7 depicts this environment. One promising new M&S initiative that will benefit SBA is specification of a High-Level Architecture (HLA) environment. Once mature, HLA will provide a common, interoperable framework for models and simulations (DMSO, 1998).

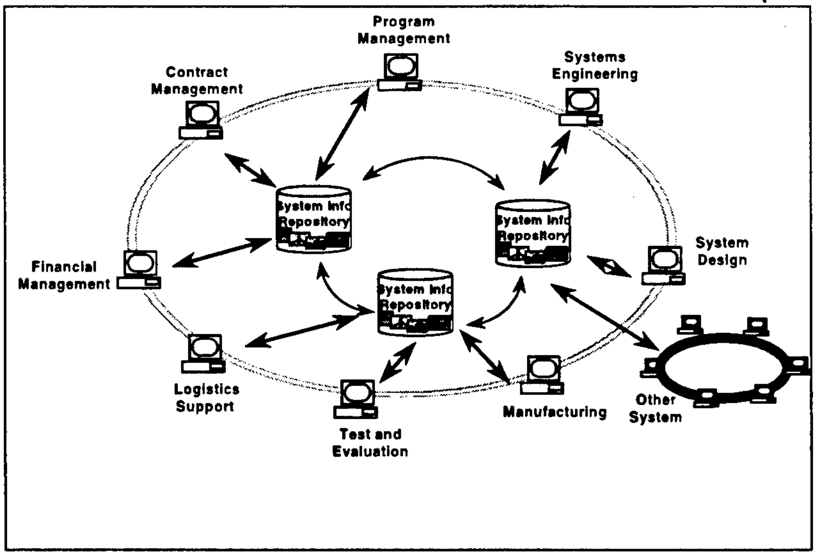

Figure 7. Advanced Engineering Environment (Frost, 1998).

Second, the acquisition and M&S communities must work together to articulate the verification, validation, and accreditation (VV&A) process for SBA that establish M&S credibility within the acquisition community. Verification determines that a model accurately represents the developer's conceptual description and specifications. Validation determines the degree to which a model accurately represents the real world. Accreditation certifies a model or simulation for a specific purpose. The responsibility for reviewing new models and simulations to ensure they produce reliable results belongs jointly to M&S developers and users. VV&A support for the acquisition community comes mainly from two agencies. The Training and Doctrine Command Analysis Center (TRAC) serves as the Army's VV&A subject matter expert (Army Regulation 5-11, 1997). As such, TRAC helps bridge technical gaps for developing reliable and credible models and simulations for SBA. DoD designated DMSO as the central management office for all Defense M&S (DoD Instruction 5000.61, 1996). DMSO provides M&S

expertise on a wide range of technical and technological issues and also serves as the DoD Modeling and Simulation Resource Repository (MSRR).

Third, the application of M&S to SBA requires reengineering the current acquisition processes. The "spiral" systems engineering method seems well-suited for integrating M&S into SBA. Applied over time, the spiral systems engineering subprocesses of concept identification, decomposition, synthesis, and integration help ensure development of acceptable products. The systems engineering process addresses the repeated questions of why, what, and how of the users, program management office representatives, and contractors as depicted in Figure 6. This allows system engineers and program mangers to continually re-evaluate mission needs, requirements, design trade-offs, improvements, and alternatives. SBA exploits the systems engineering process by compressing each iteration of the spiral through the use of constructive and virtual M&S.

For example, the Army recently employed this process. Figure 8 depicts a recent application of this process. It shows an evolutionary cycle involving continuous soldier (user) feedback linked to system development through program management and contractors. The Army tested this process through Army Warfighting Experiments (AWEs). In these experiments, program managers provided developmental technology and products for soldiers to use in training exercises. Live exercises supported by virtual and constructive simulations provided insights into the impacts of new information technologies on doctrine, tactics, techniques, and procedures.

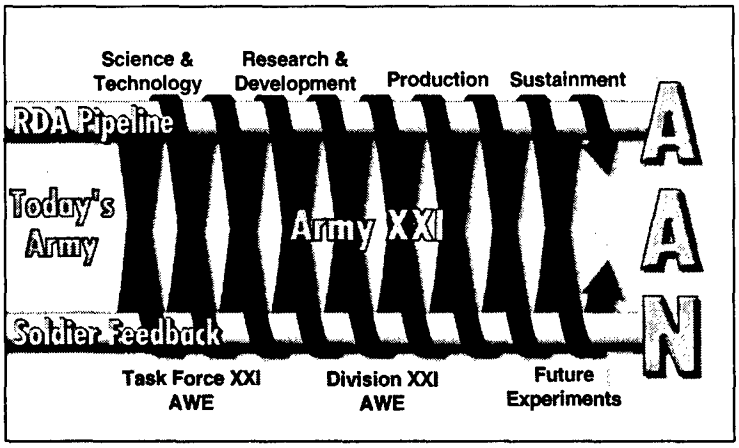

Figure 8. The Spiral Process (Kern, 1998).

Additionally, contractors, who attended the exercises, made on-the-spot changes to the equipment or suggested alternate employment methods to further improve results through this approach. This approach, referred to as "design-test-design," has been described by LTG Kern, the Military Deputy to the Army Acquisition Executive, as the spiral development process. He envisioned this process as one of the keys to SBA (Kern, 1998).

The maturing of a simulation-based environment for acquisition depends upon a number of people-related issues as well. First, applying M&S to the acquisition process requires properly educating and training acquisition personnel involved in the process. Program managers' current lack of understanding regarding the implications of M&S represents a significant obstacle to effective use of M&S. The lack of a clear vision supported by achievable objectives for applying M&S contributes to the problem. However, the recent focus of Defense acquisition officials on utilizing M&S technology combined with formal training and education will hopefully improve M&S expertise throughout the acquisition community.

Acquisition managers indicated that resistance still exists to the use of constructive and virtual M&S, especially in the OT&E environment. Acquisition personnel must feel confident that models and simulations will produce credible data and results. Scarcity of convincing evidence showing M&S as a viable alternative to actual testing, and the lack of motivation to adopt M&S for conducting evaluations, contributes to this lack of confidence. As discussed earlier, DMSO and TRAC serve as the experts for implementing sound VV&A practices that may assist in addressing M&S credibility.

The current stove-piped approach to weapon system acquisition does not efficiently produce a weapon system. Acquisition managers must apply the IPPD environment to weapon system development to facilitate the integration of M&S across functional disciplines. The IPPD environment better supports SBA through more effective communications and decision-making across all functional disciplines. Application of the IPPD environment will enable SBA to take advantage of the integration of functional disciplines across acquisition phases. These functional disciplines include contract management, test and evaluation, financial management, manufacturing, and logistics support.

G. APPLICATION OF SBA TO THE ACQUISITION PROCESS

From a theoretical standpoint, SBA can provide a new, more powerful acquisition strategy potentially leading to significant product improvements. However, this assumes a common, reusable simulation-based acquisition environment that interfaces across all functional disciplines. This SBA environment will replace the traditional disjointed, stove-piped acquisition methodology with a collaborative IPPD environment that relies

on an iterative and interactive acquisition methodology for acquiring weapon systems. This concept envisions acquisition functional domains concurrently applying M&S throughout the acquisition process as depicted in Figure 9.

To illustrate the strategy, assume the intelligence community proposes a new mission requirement reflecting improved threat capabilities. Articulating this requirement provides input parameters to models and simulations for defining and generating system operational performance requirements. Based on the new mission need, organizations such as TRADOC define performance requirements that provide a basis for developing

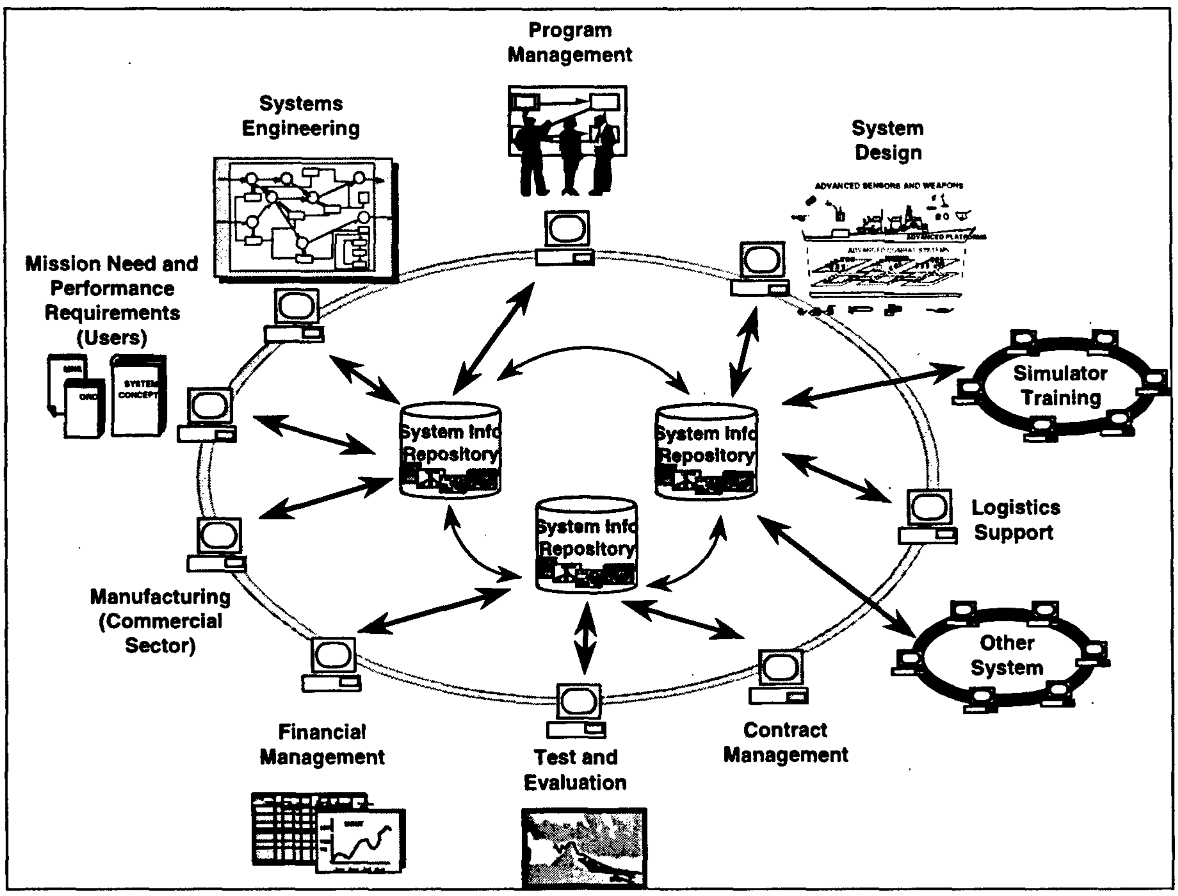

Figure 9. The SBA Environment (Frost, 1996).

and evaluating system operational and performance concepts.

During Phase 0 of the new acquisition process, system designers and engineers will electronically access performance parameters stored in an information repository to explore various design concepts. Engineers create virtual designs using CAD tools that will also reside in the information repository. Other functional discipline experts can analyze and comment on the utility of each design on-the-fly in near real-time. Program managers study data collected from initial computer design and testing to begin addressing logistics support, financial management, and manufacturing concerns. Program managers feed this analysis back into the design process to determine which concepts best meet system performance requirements. As system and subsystem designs mature, program managers conduct tradeoff analysis of cost, schedule, and performance for each design alternative.

By Phase I, the information repository contains information on operational scenarios for system testing, performance and design requirements, preliminary design solutions and associated system performance characteristics, material costs, and preliminary manufacturing requirements. The information repository provides program managers with information they need to make final design decisions based on analysis of cost, schedule and performance. In Phase I, system designers utilize engineering models to represent the weapon system in a three-dimensional, virtual environment. This gives the weapon system end-user the ability to visualize the new system and provide valuable feedback on system design. Virtual prototyping, combined with constructive simulations, will provide key insights into design modifications impact on system performance.

Significant cost savings may be realized through the use of M&S for testing at this stage rather than many iterations of live developmental tests.

In Phase II, SBA models and simulations link design and manufacturing processes and schedules. Contractors can utilize computer-aided manufacturing (CAM) methods to produce precise component prototypes and establish quality assurance guidelines for Statistical Process Control (SPC). Also during this phase, M&S supports configuration management through documentation of design changes leading to the final design. SBA makes it much easier to record and update the information repository for such things as design changes, system cost analysis, and performance evaluations. Through the information repository, this information becomes instantly available to other program managers, system users, and commercial contractors.

Operational testing involves evaluating the system in a either a live, virtual, or constructive simulation environment. Data gathered from virtual testing provides engineers with insights into performance characteristics and is useful for making design changes. Within a mature SBA environment, conducting operational testing in a virtual environment can be accomplished at a much lower cost compared to live operational testing.

During Phase III, results from field testing of system prototypes are added to the information repository along with final blueprints of the weapon system, and detailed documentation of the complete acquisition process. This information may be shared for future use. If the weapon system requires major modifications, program managers could

access historical system data when conducting future cost and performance evaluations of proposed changes, making design modification decisions, and production-line restarts.

Throughout all acquisition phases, SBA will provide a system development environment for more effectively managing cost, performance, and schedule. This environment will be distributed and decentralized, not accomplished just from one location. Finally, it will provide program managers with access to use and reuse M&S data and products. This will reduce or eliminate costs associated with developing future models and simulations for specific applications.

H. APPLICATIONS OF SBA-LIKE ENVIRONMENTS

Examples of industry–related SBA ventures made thus far include International Business Machines' (IBM) development of the Computer-Aided, Three-Dimensional Interactive Application (CATIA) to assist companies in utilizing the digital environment to efficiently produce quality products. As depicted in Figure 10, CATIA utilizes a centralized information database and consists of modular computer applications that form an integrated design, analysis, and manufacturing system. Users enter market data, field services (logistic support), and supplier's parts or components into the database. Engineers use database information to create virtual designs. Analysis of designs may yield insights into cost, schedule, and performance to improve selection of an optimal and cost-effective solution.

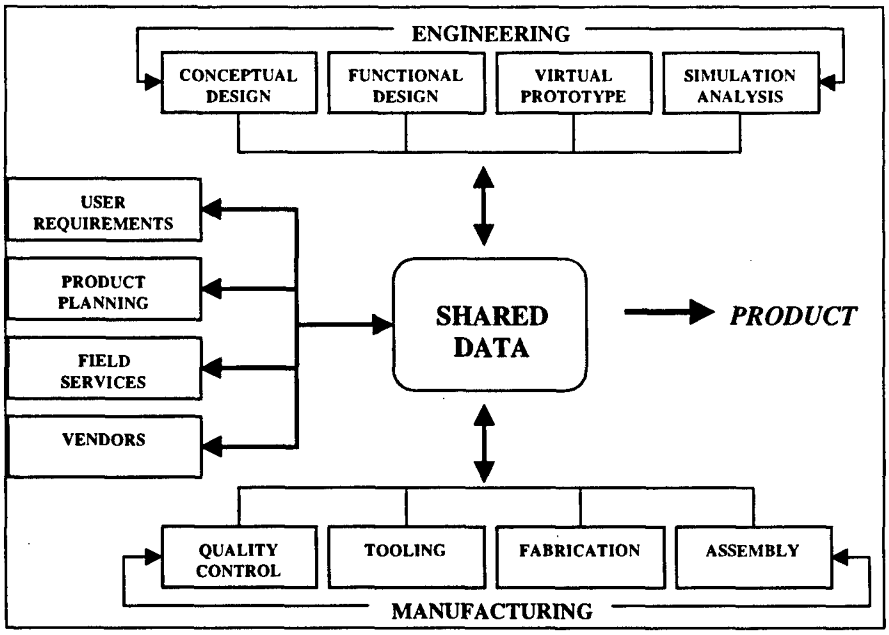

Figure 10. IBM's CATIA Software (Garcia, 1993).

CATIA database information can be accessed from distributed work-stations. Engineers, manufacturers, users, suppliers, financial managers, and analysts can all access information and make-decisions based on the most current design. Manufacturers can use final digital designs to develop unique tools and machines required for manufacturing and fabricating parts and components, assembly machines, and to define quality control.

The Defense Advanced Research Projects Agency (DARPA) also conducted a SBA-like project to develop and validate a reusable, distributive, and collaborative process for designing weapon systems. The intent of the project was to develop and demonstrate a reusable framework that employs the IPPD environment, common applications, decentralized communication, and virtual prototypes in synthetic environments for the design, test, and fabrication of a product.

Lockheed Martin, selected by DARPA to lead development, successfully linked multiple tools across seven major areas: mission analysis, propulsion plant selection, collaborative design, distributive interactive simulation interactions, multi-disciplinary analysis, manufacturing analysis, cost analysis, and risk analysis (NATIBO, 1996). Lockheed validated the framework it developed) utilizing a notional, advanced-surface-combatant ship concept. Figure 11 overviews the project architecture.

Much of DoD's SBA framework discussed previously in this chapter came from the commercial sector's efforts to apply M&S to the acquisition process. One noteworthy commercial SBA venture was Boeing's design and development of the 777 passenger aircraft as depicted in Figure 12. This venture exemplifies how the SBA approach reduced both cost and development schedule, and improved performance.

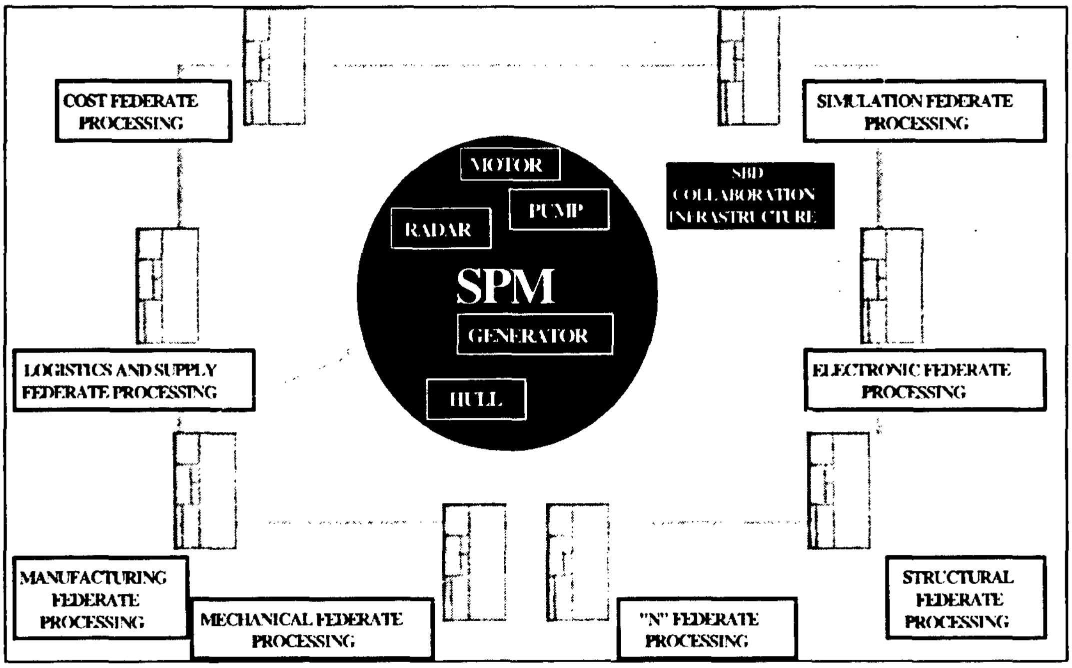

Figure 11. SBD Architecture (Jones, 1997).

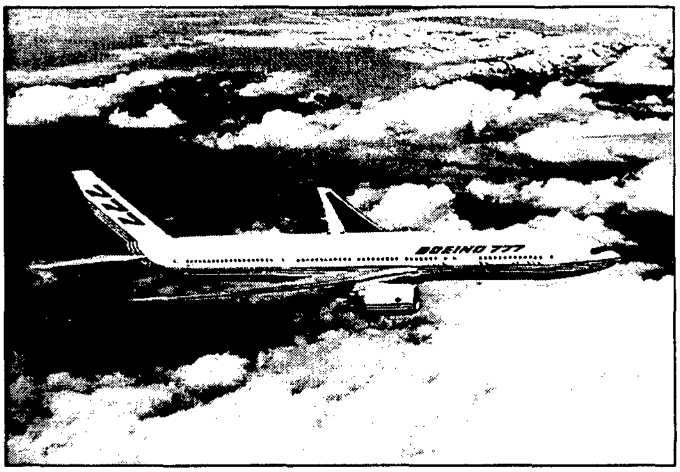

Figure 12. Boeing 777 Aircraft (Boeing, 1998).

Boeing produced the first digitally-designed commercial passenger aircraft through the use of CATIA's synthetic environment. CATIA allowed Boeing to fully design the complete aircraft on a computer. In one instance, Boeing capitalized on the CATIA environment by utilizing a synthetic mechanic to run simulations on the maintainability of the aircraft. Boeing found the computer-generated mechanic could not reach a particular navigation light in order to change the light bulb. By making necessary changes before ever building a single aircraft, engineers fixed this problem. Boeing also utilized the synthetic environment to check for interference between all parts of the aircraft. In one case this led to a decrease in assembly time from nineteen weeks to just three weeks.

The CATIA application fostered the SBA concept of integrating functional disciplines across program phases. Through the use of design-build teams, Boeing not only forced design and manufacturing engineers to work side-by-side in the digital environment, but it also required suppliers and customers to participate throughout the

entire process. Compared to producing other aircraft, Boeing reduced error and rework by 50%, delivered the first aircraft ahead of schedule, and kept total cost within budget (Marvil, 1998).

The Grizzly represents one of the Army's first attempts to utilize SBA in an ACAT II program. The Grizzly, built upon an M1 tank platform, is an obstacle breaching vehicle that features an automatic, depth-controlled, articulated mine clearing blade, and a telescoping excavating arm. Figure 13 depicts the system prototype.

The program originally applied M&S in a disjointed and limited fashion. The program manager, Lieutenant Colonel (LTC) Kotchman, recognized the benefits of SBA and applied them, where possible, to the Grizzly acquisition process. LTC Kotchman assumed control of the program in Phase II of the acquisition process. He immediately focused on solving critical technical problems associated with the automatic depth control, systems integration, and man-machine interface (Kotchman, 1998).

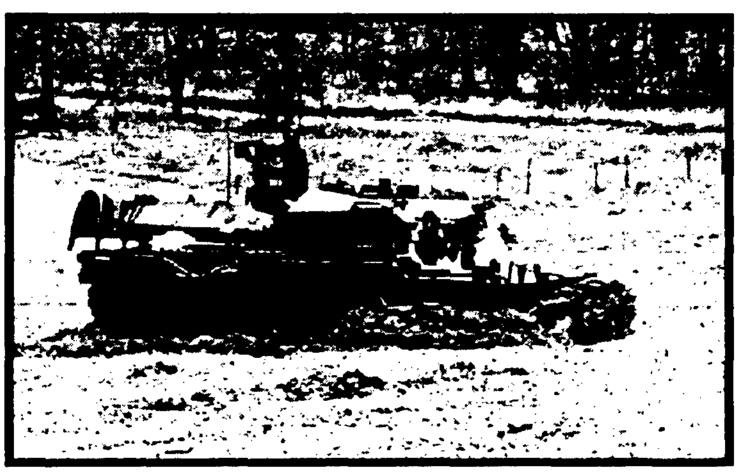

Figure 13. The Grizzley.

Through the use of models and simulations, the program manager evaluated characteristics of different hydraulic, suspension, chassis, and blade designs in simulated terrain. The Grizzly program interactively linked, for the first time, component level M&S products including a Computer Aided Project Engineering (CAPE) model, a propulsion, track, and suspension model called Dynamic Analysis and Design System (DADS), and *Davis*, a United Defense Limited Partnership proprietary terrain-animation model. The Grizzly program benefited from the application of interactive M&S by reducing a four-month, three-million dollar soils plowing study, to a one-day, three-hundred-thirty thousand dollar study. In another instance, the program utilized M&S to simulate components to reduce production interference errors during manufacturing. According to LTC Kotchman, the Simulation Support Plan (SSP) and M&S removed the 'fog of uncertainty" surrounding many technical and operational aspects of the process ultimately leading to reductions in cost and schedule, and performance enhancements (Kotchman, 1998).

I. SBA RISKS AND BARRIERS

Thus far, this thesis discussed benefits associated with implementing a simulation-based acquisition strategy. Acquisition program managers must also consider possible risks to implementing SBA. First, program managers cannot rely on constructive and virtual M&S for all acquisition related tasks. For example, DoD cannot rely exclusively on modeling and simulation for OT&E (DoD Regulation 5000.2-R, 1998). Program managers must fully understand current and applicable policies and laws that govern the use of models and simulations.

Second, data descriptions of some fielded equipment are not available. In other cases, managers have non-digital data descriptions. Program managers may find the cost of generating data descriptions or converting non-digital descriptions for legacy systems excessive. Further, utilizing unverified and invalid data descriptions could result in decreased system performance and increased costs.

Third, program managers may face challenges in providing security for M&S technologies and resulting data. Some contractors retain proprietary control of computer models and simulations that they develop. This may cause configuration problems for re-use as well as associated costs. Also, since program managers conduct SBA in a distributive fashion, breaches of the information repository pose a security threat that program management personnel must address.

Fourth, some software programmers did not base their model or simulation on physical properties. Instead, they based them on evidence gathered from other sources. This may create a situation where the model or simulation does not correctly interpret user-entered data, thus producing questionable or unreliable outputs. Movement towards more physics based models and simulations, rather than those based on historical data, will help provide greater acceptance in the acquisition community.

J. SUMMARY

The acquisition community only recently began to realize the potential impacts of SBA on the acquisition process. Continued improvements in technology and the appropriate application of M&S in an IPPD environment will solidify SBA as a method to develop and deploy complex weapons systems. Once fully developed, SBA will

provide the acquisition community with a new paradigm for significantly reducing both the acquisition cycle and costs while helping to develop a higher-quality, higher-performing product. However, these benefits also incur risks: lack of funds to fully develop and utilize M&S tools, inaccurate data descriptions, improper application of M&S tools, and security breaches of information repositories. The acquisition community must carefully consider both benefits and risks when developing a strategy for implementing SBA.

IV. SIMULATION-BASED ACQUISITON RESEARCH LABORATORY

A. INTRODUCTION

Chapter III discussed technological, cultural, and procedural barriers to implementing SBA. DoD's focus on acquisition reform and sponsored research into modeling and simulation, computer, and communication technologies will contribute to overcoming barriers and accelerate the adoption of SBA as a strategy for weapon system acquisition. Another important area where the acquisition community has not yet fully realized the potential benefits of a SBA strategy is through the development of a simulation-based acquisition research laboratory. This type of laboratory can assist DoD and program managers' efforts to exploit models and simulation for weapon system acquisition experimentation and program management.

B. DEFENSE RESEARCH LABORATORIES

DoD sponsors research to assist in technically-challenging, problem solving. Through DARPA, DoD spends over two-billion dollars annually to develop projects that will support current and future military needs. Further, the Army, Navy, and Air Force operate research laboratories to study technological areas that are relevant to their particular missions. For instance, the Air Force utilizes four laboratories:

- *Armstrong Laboratory,* located at Brooks Air Force Base, Texas, focuses on human-machine integration problems.
- *Phillips Laboratory*, located at Kirtland Air Force Base, New Mexico, deals with space and missile related research including geophysics, propulsion, and direct-energy weapons.

- *Rome Laboratory*, located at Griffis Air Force Base, New York, specializes in research and development of command, control, communications, and intelligence (C^3I) programs.
- *Wright Laboratory*, located at Wright-Patterson Air Force Base, Ohio, conducts research and development of aeronautical technologies.

These laboratories conduct cutting-edge research leading to development of new, state-of–the-art technology for the Air Force, contributing to development of new products and processes and improving mission success. Other laboratories include the Army Research Laboratory (ARL), Construction Research and Engineering Laboratory (CERL), Naval Aerospace Medical Research Laboratory (NAMRL), and Biomedical Research & Development Laboratory.

Although each of these laboratories has a specific technological orientation, they all accomplish a common mission. Key objectives include the following: *Discover* enabling technologies that offer potential for revolutionary improvements in weapon systems; *Develop* and demonstrate advanced technologies for current and future requirements; *Transition* proven technologies to program managers; and *Solve* pressing technological problems.

DoD research laboratories also form partnerships with academia and industry to assist in meeting these objectives. For example, ARL funded the University of Pennsylvania to develop a human performance model called *Jack*. The National Aeronautical and Space Administration (NASA) and the Tank Automotive Research, Development, and Engineering Center (TARDEC) both integrated *Jack* into their CAD

systems to research man-machine compatibility design issues (ARL, 1997). ARL and other laboratories also fund M&S technology and interoperability research. Although many research and development efforts support specific technical applications of technology, no strategic and holistic research program exists for SBA.

C. SIMULATION-BASED ACQUISITION RESEARCH LABORATORY

The SBA research laboratory environment may provide a concerted means to improve development and implementation of SBA. A simulation-based acquisition research laboratory would provide a proving-ground to develop, validate and implement the SBA process. Key research to be exploited by a SBA research laboratory are discussed below.

- *Discovery.* This involves exploiting new M&S, computing, and communications technologies. Laboratory research would develop and test technologies that could assist in refining the SBA strategy to assist program managers in acquiring weapon systems more efficiently. The laboratory would capitalize on an advanced engineering environment to facilitate M&S integration and re-use across functional disciplines and programs for all Services.
- *M&S Development.* Demonstrating SBA concepts using state-of-the-art M&S technologies to improve acquisition processes, the laboratory would simulate the acquisition process across functional disciplines to virtually design, analyze, and test system concepts.
- *Technology Integration.* As the laboratory validates the SBA process and products, M&S components could then be exported to acquisition programs.

Laboratory modularity will allow reconfiguration and integration of new technologies as they become available for specific adaptation to unique program requirements.

- *Problem Solving.* Applying new SBA technologies to improve business processes will create new problems. By using the laboratory to test new technology and integrate them with other components of SBA, the laboratory will not only solve complex technical problems but also address practical problems that occur when conducting acquisition across all functional disciplines and phases.

With these four objectives in mind, the SBA research laboratory would provide insights into six key domains described below and depicted in Figure 14:

- *Command, Control, Communication, Computer, Intelligence, and Reconnaissance (C4SIR).* Discover, develop and transition state-of-the-art technologies to assist program managers in utilizing high-speed, networked, data environments.

- *Acquisition Methodology.* Evaluate M&S impacts on acquisition methodologies and propose new, more efficient methodologies for weapon systems procurement.

- *Prototyping and Manufacturing.* Research and develop M&S products that will further exploit virtual prototyping and manufacturing of weapon systems.

- *Knowledge Mall.* Develop and provide a one-stop, virtual "shopping mall" where users could access and utilize stored SBA or M&S related information such

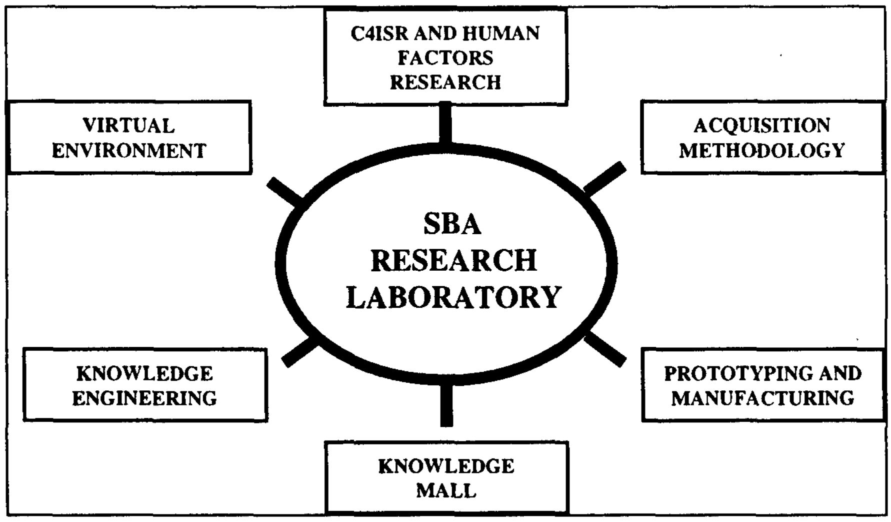

Figure 14. SBA Research Laboratory Domains.

as reusable data descriptions, models, simulations, and other pertinent acquisition information.

- *Knowledge Engineering.* Discover, develop, and transition M&S products that support the functional analysis of the proposed weapon system.
- *Virtual Environment.* Discover, develop, and transition collaborative products to support the visualization of the weapon system focusing on emerging virtual reality technologies.

In addition to providing research into these domains, the research laboratory would also provide a capability to initially test the SBA environment and assist the acquisition community in developing, designing, fielding, managing weapon systems. The SBA research laboratory would support defense acquisition through the "top-gun" approach by concurrently researching, developing, and testing SBA focusing on a federation of applications, high-speed distributive communications, collaborative environments, and IPPD.

Figure 15 depicts the research laboratory which, through collaboration with academia and industry, pursues and applies the necessary standards and protocols, architecture, infrastructure and digital descriptions required to create the federation of applications. This federation of applications supports seamless and virtual development, analysis, and production of weapon systems. Once acquisition personnel create the weapon system, the digital blueprint becomes part of the knowledge mall. Additionally, as M&S applications are utilized for running distributive training simulators, performing operational analysis, and analyzing future system upgrades, resultant data would be fed

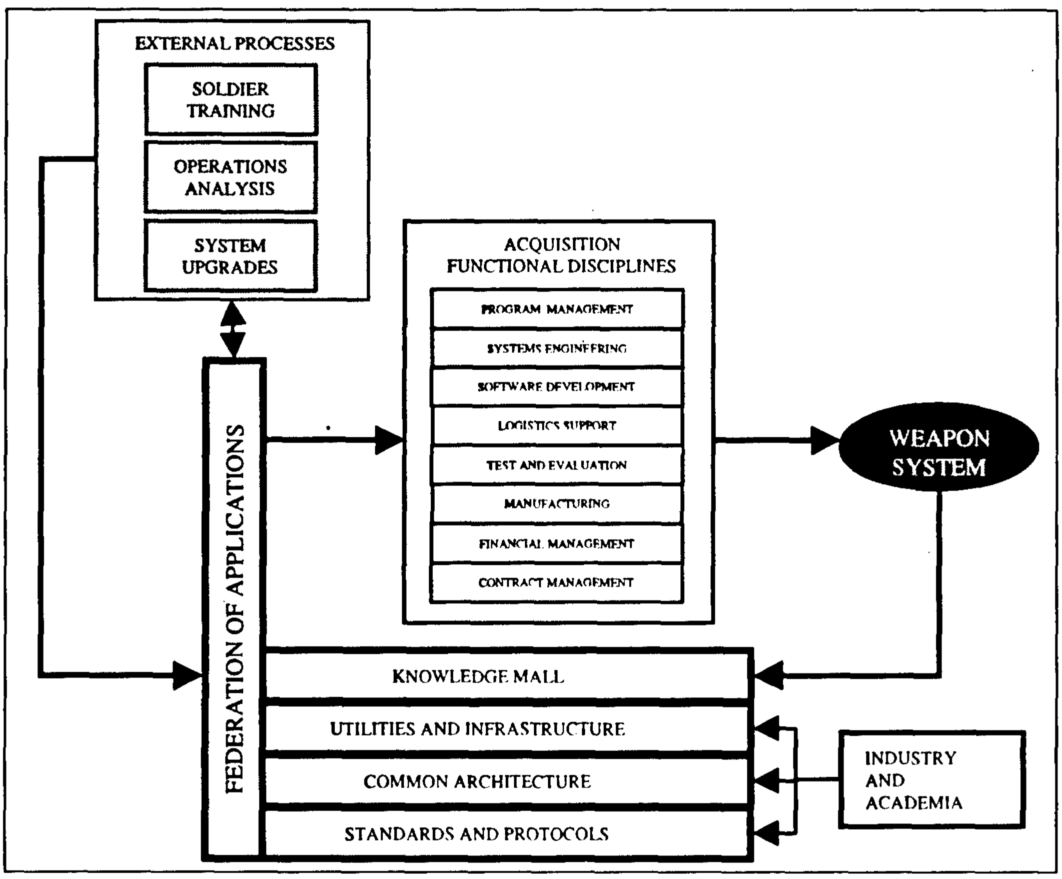

Figure 15. Laboratory Environment.

back into the knowledge mall. Development of the federation of applications provides a virtual environment with necessary interactivity to seamlessly support all phases of the acquisition process as well as soldier and crew training, operations analysis, and system upgrades.

Figure 16 depicts a high-level architecture for the SBA research laboratory. This architecture reflects a laboratory environment for not only conducting research and development into each of the domain areas but also conducting proof-of-principle demonstrations. To provide the SBA capability, the laboratory would consist of computer stations and high-fidelity, graphic-visualization displays that will provide information to acquisition functional areas such as test and evaluation or logistics analysis. Networked computers would provide varying levels of fidelity based on user needs.

Networked computers also facilitate creation of a "knowledge mall." In concept, the knowledge mall would provide one-stop access to stored information such as data descriptions, terrain data, and models and simulations necessary to conduct SBA. Capitalizing on state-of-the-art computing and communication technology, this SBA proving-ground could either be centralized or decentralized. Further, other organizations such as training units, battle labs, and acquisition programs, could connect to the network from distant sites to participate in ongoing SBA activities or access specific products in the resource repository.

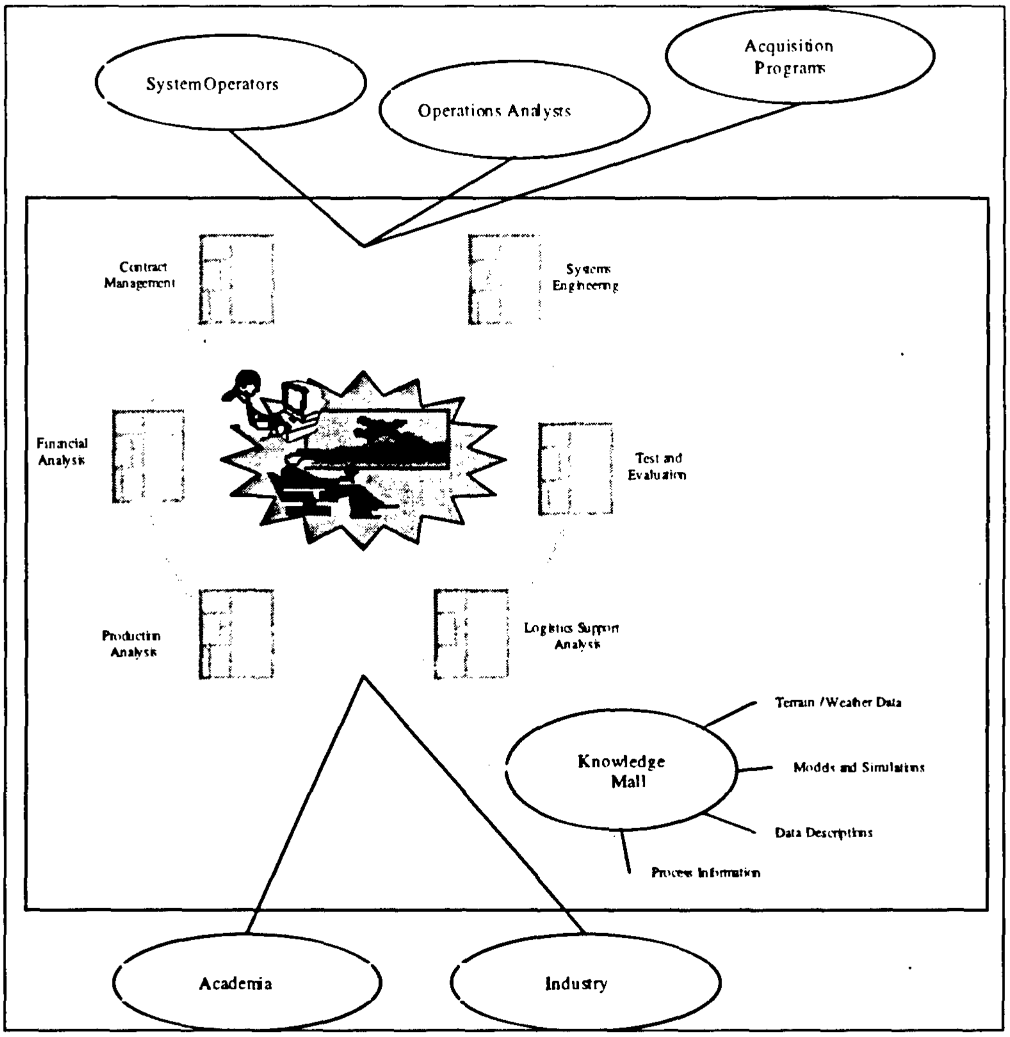

Figure 16. SBA Research Laboratory Architecture.

Figure 17 diagrams the laboratory process. The laboratory environment consists of all items in the shaded region of Figure 17. Products and interfaces with other agencies are depicted outside of the shaded area. The laboratory environment interfaces with industry and academia to investigate state-of-the-art technologies, acquisition and engineering knowledge, and improving processes that contribute to the creation and success of SBA. The knowledge mall, computer network, and visualization capability

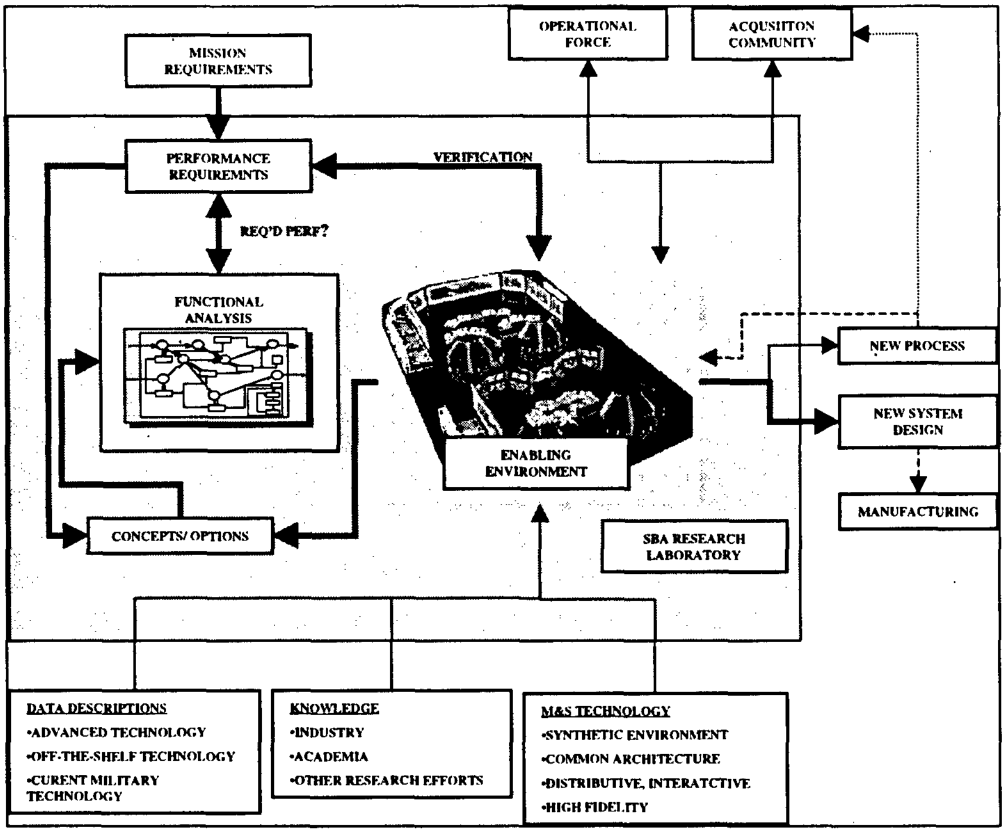

Figure 17. SBA Laboratory Process.

combine to create the enabling environment. Within this environment, managers could conduct simulation-based acquisition.

From a process perspective, the requirements community feeds mission needs into the laboratory. Laboratory personnel conduct virtual systems engineering, develop performance requirements, and design concepts to meet DoD needs. Personnel also conduct functional analysis of concept designs to assist in eliminating designs or design elements that do not meet specific performance objectives.

Functional disciplines, such as financial management and logistics support, also represent potential research areas for conducting risk analysis and mitigation as well as trade-off studies. This analysis helps narrow design concepts and alternatives to ones that

best meet cost, performance, and schedule requirements. Researchers conduct simulated test and evaluation on completed designs, verifying that the virtual system meets required performance, operational effectiveness, and operational suitability thresholds. A modular design will enable the laboratory to incorporate emerging virtual reality technology. This would further enhance the ability of the laboratory to measure design suitability and resolve man-machine interface problems. Digital system design research would provide opportunities to model computer-aided manufacturing processes. It may also be possible to link industry with the laboratory environment to capture electronic designs necessary to produce parts and components for the complete system.

Through the SBA research laboratory, it will be possible to design a new weapon system in a virtual environment and also develop new business processes. New business practices, derived from lessons learned in conducting IPPD as part of the SBA environment, would provide greater efficiency to the acquisition process. The laboratory would then feed these new business processes back to the acquisition community and the enabling environment for further refinement of the acquisition process.

D. SUMMARY

The SBA research laboratory concept is an important component of SBA integrating best M&S technologies and practices across all services, industry and academia. It would assist the acquisition community in implementing the SBA strategy while providing a virtual proving-ground for conducting SBA prototyping. The SBA research laboratory represents a centralized research facility for discovering, developing, transitioning and solving pressing SBA related technological and process issues. Finally,

it provides an environment to accelerate the development, adoption, and implementation of SBA.

V. CONCLUSION

A. OVERVIEW

Traditional Defense acquisition methodology, combined with declining defense budgets and increasing weapon system complexity, created a resource intensive acquisition process. To combat this problem, DoD implemented acquisition reforms, such as the IPPD environment, to reduce resources necessary to acquire weapon systems. DoD recognized that computer models and simulations saved or mitigated costs, assisted in reducing cycle-time, and helped improved product performance. However, DoD did not fully appreciate the benefits of a synchronized M&S environment for acquiring weapon systems.

Historically, program managers applied modeling and simulation in a disjointed, stove-piped fashion. Acquisition programs developed computer models and for specific functional uses and often did not consider interface or re-use applications. Given advances in computing technologies, communication networks, and Defense methodologies for weapon system acquisition, a new paradigm emerged, that of simulation-based acquisition.

SBA capitalizes on the IPPD culture, a spiral or evolutionary methodology, and an advanced technological environment. It provides modeling and simulation assets necessary to support the concept development, risk reduction, engineering, and manufacturing of a system across all functional disciplines. SBA accomplishes this through integrated and distributive technologies rooted in the IPPD environment. SBA

will provide the acquisition community with the strategy to acquire weapon systems faster, cheaper, and with higher performance.

B. BENEFITS

The traditional acquisition methodology does not support the SBA concept. The highly linear nature of this methodology does not facilitate the integrated, cross-functional approach required by the virtual environment. SBA functionality reflects a process that compresses the acquisition cycle through the use of IPPD and a model-test-model approach. More useful methodologies are either the evolutionary or spiral processes, where iterative applications of systems engineering processes occur over time until the most cost-effective and operationally-effective concept emerges.

Program managers often developed and utilized unique modeling and simulation applications that did not support re-use across phases, disciplines, or programs. By creating a federation of interactive computer models capitalizing on advancements in computer and communication technologies, a distributive and collaborative virtual environment can be created. This SBA environment would provide necessary applications to conduct near simultaneous design, analysis, and testing of a concept system across all functional disciplines.

Following a SBA approach to weapon system acquisition presents program managers with both risks and benefits that must be addressed. Nonetheless, the benefits seem to greatly outweigh the risks. Through application of computer models and simulations, program managers will reduce cycle-time and costs, and improve system

performance. Reliance on the IPPD process will foster greater cooperation among all stakeholders to produce a more effective system.

Results suggest SBA has the potential to reduce system acquisition cycle-time by fifty percent, lower costs, and increase system performance. However, an integrated SBA environment is not currently available. Therefore, DoD develop an integrated computing, software, communications, and business environment to fully realize the potential of SBA.

To this end, a SBA research laboratory will assist DoD and program managers with facilitating development and implementation of SBA. Through centralized efforts to synchronize SBA elements across all Services, the research laboratory could accelerate the development and implementation of SBA. The laboratory could provide technical assistance, training, and education opportunities to program offices that wish to utilize M&S products or apply SBA strategies. The laboratory also serves as a research center for virtual environments, evaluating combinations of technologies and business practices.

C. RECOMMENDATIONS

SBA will provide the program manager with a viable and potentially powerful strategy to mitigate risks and render a more timely, cost-effective weapon system. As SBA continues to evolve and mature with improvements in computers, information technology, and software, Defense acquisition officials must continue to facilitate this maturation by providing the leadership and resources to develop and define the enabling architecture required to fully integrate different models and simulations.

- DoD must incentivize M&S investment. Incentives will motivate program managers to explore and implement models and simulations when appropriate.
- DMSO must continue to serve as the focal point for M&S technology management. It should synchronize SBA efforts across all Services to assist in removing redundancy and accelerating the development of this acquisition strategy.
- DMSO should create a SBA research laboratory environment. This laboratory would assist in synchronizing and coordinating M&S related research efforts to produce the SBA environment. It would accelerate the adoption and implementation of a SBA strategy and provide the acquisition community with a focal point for this new concept.
- The acquisition community must continue to mandate the use of M&S when appropriate. Education and training of acquisition professionals, testers and evaluators, and users alike will help make M&S a more accepted and understood tool and overcome biases toward M&S.
- Program mangers should develop a strategy early on to incorporate the interactive use of M&S technologies across all phases and functional disciplines. The SSP represents a critical document for communicating this strategy.
- Program managers must implement the IPPD environment to fully realize the potential of SBA. The program manager must involve all stakeholders including, users, testers, and suppliers in the acquisition process as early as possible.

- Program mangers must secure M&S program funding. The SSP will assist in defining the required models and simulations and projecting the associated costs of obtaining and operating these programs.

D. AREAS FOR FURTHER RESEARCH

The following areas may provide additional research opportunities for SBA related topics:

- Further investigation of current progress toward implementing the technologies required to create the SBA environment is warranted. Since the elements of SBA are evolving at a rapid rate, further research would provide new insights into areas that challenge the implementation of SBA. Results of this research could suggest methods for overcoming these problems.
- Compare a traditionally developed weapon system with one developed using the SBA strategy. This research would provide a detailed cost-benefit analysis between the two approaches to quantify the actual benefits of SBA, and discuss lessons learned from the implementation of SBA.
- Further development of a SBA research laboratory architecture may prove useful to DoD. Research the development of lower-level functional requirements and interfaces to provide a more detailed laboratory architecture. Additional research into available, enabling technologies and their integration into the laboratory would provide DoD with a blueprint for moving from concept to reality.

APPENDIX

AE	Acquisition Executive
AMSO	Army Modeling and Simulation Office
ARL	Army Research Laboratory
ATD	Advanced Technology Demonstration
AWE	Army Warfighting Experiment
C3I	Command, Control, Communications, and Intelligence
C4SIR	Command, Control, Communication, Computer, Intelligence, and Reconnaissance
CAD	Computer Aided Design
CAIV	Cost as An Independent Variable
CAM	Computer Aided Manufacturing
CAPE	Computer Aided Project Engineering
CASTFOREM	Combined Arms Support Task Force Evaluation Model
CATIA	Computer-Aided, Three-Dimensional Interactive Application
CERL	Construction Engineering and Research Laboratory
CINC	Commander-in-Chief
DADS	Dynamic Analysis and Design System
DARPA	Defense Advanced Research Projects Agency
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DSMC	Defense Systems Management College
DT&E	Developmental Test and Evaluation
EC	Electronic Commerce
EDI	Electronic Data Interchange
EMD	Engineering and Manufacturing Development Phase
FAR	Federal Acquisition Regulation
FASA	Federal Acquisition Streamlining Act of 1994
FCIM	Flexible Computer-Aided Integrated Manufacturing
GWEF	Guided Weapons Facility
HLA	High-Level Architecture
HW	Hardware

IBM	International Business Machines
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
JCS	Joint Chiefs of Staff
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
JTA	Joint Technical Architecture
LRIP	Low Rate Initial Production
M&S	Modeling and Simulation
MAA	Mission Area Analysis
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MNS	Mission Need Statement
MSRR	Modeling and Simulation Resource Repository
MTS	Moving Target Simulator
NAMRL	Naval Aerospace Medical Research Laboratory
NASA	National Aeronautical and Space Administration
NATIBO	North American Technology and Industrial Base Organization
NDIA	National Defense Industrial Association
OMB	Office of Management and Budget
OT&E	Operational Test and Evaluation
PDRR	Program Definition and Risk Reduction
PM	Program Manager
PMO	Program Management Office
REFORGER	Return of Forces to Europe
SBA	Simulation-Based Acquisition
SBD	Simulation-Based Design

SPC	Statistical Process Control
SSP	Simulation Support Plan
STEP	Simulation Test and Evaluation Process
SWIL	Software in the Loop
TARDEC	Tank Automotive Research, Development, and Engineering Center
TACOM	Tank Automotive Command
TRAC	Training and Doctrine Analysis Center
TRADOC	Training and Doctrine Command
USD(A&T)	Under Secretary of Defense (Acquisition and Technology)
VIC	Virtual Individual Combatant
VV&A	Verification, Validation, and Accreditation
WAAM	Wide-Area, Anti-Armor Munition

LIST OF REFERENCES

Department of the Army Homepage, ARL, http://www.arl.mil/ARL-Directorates/HRED/jack.html, 9 December 1997.

Boeing Corporation Homepage, http://www.boeing.com/companyoffices/gallery/images/commercial/777.htm, 17 October 1998.

Department of Defense, "Acquisition Deskbook" CD-ROM, Version 2.3, March, 1998.

Department of Defense Directive 5000.1, "Defense Acquisition," March 1996.

Department of Defense Instruction 5000.61, "DoD Modeling and Simulation Verification, Validation, and Accreditation," 29 April 1996.

Department of Defense Regulation 5000.2-R, "Mandatory Procedures for Major Defense Acquisition Programs and Major Automated Information System Acquisition Programs," March 1998.

Department of Defense Directive 5000.59, "DoD Modeling and Simulation Management," January 1994.

Department of Defense Directive 5000.59-P, "Modeling and Simulation Master Plan," October 1995.

Department of Defense Homepage, DMSO, http://www.dmso.mil, 19 October 1998.

Frost, Robin L., Systems Engineer, Office of the Under Secretary of Defense (Acquisition and Technology), "Simulation Based Acquisition," Unpublished Briefing, 4 May 1998.

Gansler, Jacques S., Under Secretary of Defense (Acquisition and Technology), "Life-Cycle Modeling and Simulation – A Key Element in Acquisition Reform," Remarks to the National Defense Industrial Association Simulation-Based Acquisition Workshop, Orlando, Florida, March 1998.

Garcia, Albert B., Gocke, Robert P., and Johnson, Nelson P., "Virtual Prototyping: Concept to Production," Defense Systems Management College, 1 June 1993.

Jones, Gary W., PM SBD, DARPA, "Simulation-Based Design," Unpublished Briefing, October 1998.

Kaminski, Paul G., Statement before the House Committee on National Security on Defense Acquisition Reform, Washington D.C., February 1997.

Karangelen, Nicholas E., Trident Systems Incorporated "The Simulation-Based Acquisition Vision and an Integrated Engineering Environment," Unpublished Briefing, 1997.

Kern, Paul G., LTG, Army Acquisition Executive, "Simulation Based Acquisition: Fielding a Capability Based Force," Unpublished Briefing, 1998.

Kotchman, Donald P., Lieutenant Colonel, PM Grizzly Program, "EMD Key to Success – Simulation Based Acquisition in Support of the Grizzly," Unpublished Briefing, April 1998.

Kotchman, Donald P., and Glasgow, Wesley L., "Applying Modeling and Simulation to the Grizzly Program," Army RD&A, p. 33, January – February 1998.

Marvel, Orin, Professor, Naval Postgraduate School, "The 777" Case Study, June 1998.

Mercer, Joseph G., Piplani, Lalit K., and Roop, Richard O., "Systems Acquisition Manager's Guide for the Use of Models and Simulations," Defense Systems Management College, September 1994.

North American Technology and Industrial Base Organization (NATIBO), "Collaborative Virtual Prototyping Sector Study: An Assessment of CVP Technology, Integration, and Implementation," May 1996.

Portman, Helmut H., Study Chairman, American Defense Preparedness Association, "Study on the Application of Modeling and Simulation to the Acquisition of Major Weapon Systems," September 1996.

Roberts, Michael D., Office of the Assistant Secretary of the Navy (Research, Development, and Acquisition) for Acquisition Reform, "Simulation-Based Acquisition," Unpublished Briefing, 19 June 1998.

Sanders, Patricia, Director, Defense test, System Engineering and Evaluation ,"Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process," Department of Defense Report, October 1996.

Schmoll, Joseph H., "Introduction to Defense Acquisition Management," Defense Systems Management College, June 1996.

Shokralla Shad H., University of California Homepage, http://www1.needs.org/develop/b777/ main.html, "21st Century Jet, The Boeing 777," 26 January 1997.

United States Army Regulation 5-11, "Management of Army Models and Simulations," August 1997.

United States Code, Title 10, 1989.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
   8725 John J. Kingman Road, Ste 0944
   Fort Belvoir, VA 22060-6218

2. Dudley Knox Library.. 2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, CA 93943-5101

3. COL (Ret) David F. Matthews, Code SM/MD.. 1
   Naval Postgraduate School
   Monterey, CA 93943-5000

4. Professor David Lamm, Code SM/LT.. 5
   Department of Systems Management
   Naval Postgraduate School
   Monterey, CA 93943-5000

5. LTC Michael L. McGinnis 1
   US Army TRAC-Monterey
   PO Box 8692
   Monterey, CA 93943-0692

6. MAJ Andrew J. DiMarco 3
   3 Tricia Road
   North Falmouth, MA 02556-2708